US006745751B2

(12) **United States Patent**
Seo et al.

(10) **Patent No.: US 6,745,751 B2**
(45) **Date of Patent: Jun. 8, 2004**

(54) **HIGH PRESSURE FUEL SUPPLYING APPARATUS FOR INTERNAL COMBUSTION ENGINE AND METHOD FOR CONTROLLING THE APPARATUS**

(75) Inventors: **Hiromitsu Seo**, Toyota (JP); **Masanao Idogawa**, Toyota (JP)

(73) Assignee: **Toyota Jidosha Kabushiki Kaisha**, Toyota (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/455,529**

(22) Filed: **Jun. 6, 2003**

(65) **Prior Publication Data**

US 2004/0000289 A1 Jan. 1, 2004

(30) **Foreign Application Priority Data**

Jun. 28, 2002 (JP) 2002-190258

(51) **Int. Cl.**^{7} **F02D 41/06**; F02M 37/08
(52) **U.S. Cl.** **123/456**; 123/506; 123/179.17
(58) **Field of Search** 123/446, 447, 123/456, 458, 497, 506, 179.17

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Primary Examiner—Weilun Lo
(74) *Attorney, Agent, or Firm*—Kenyon & Kenyon

(57) **ABSTRACT**

A fuel pump draws pumps fuel from a fuel tank to a pressurizing chamber during a suction stroke, and pressurizes and sends fuel in the pressurizing chamber to a delivery pipe. A electromagnetic valve is actuated by electricity from a battery to electively connects and disconnects the fuel tank with the pressurizing chamber. An ECU determines opening and closing timing of the electromagnetic valve based on the rotation al phase of an engine. When the rotational phase of the engine is not identified, the ECU executes a duty control to cyclically repeat supplying and stopping of current to the electromagnetic valve. The ECU extends a current supplying period in each cycle of the duty control as the voltage of the power supply is lowered. As a result, the electromagnetic valve is reliably closed particularly at each pressurizing stroke, which improves the pressure increasing efficiency of fuel supplied to a fuel injection system.

17 Claims, 12 Drawing Sheets

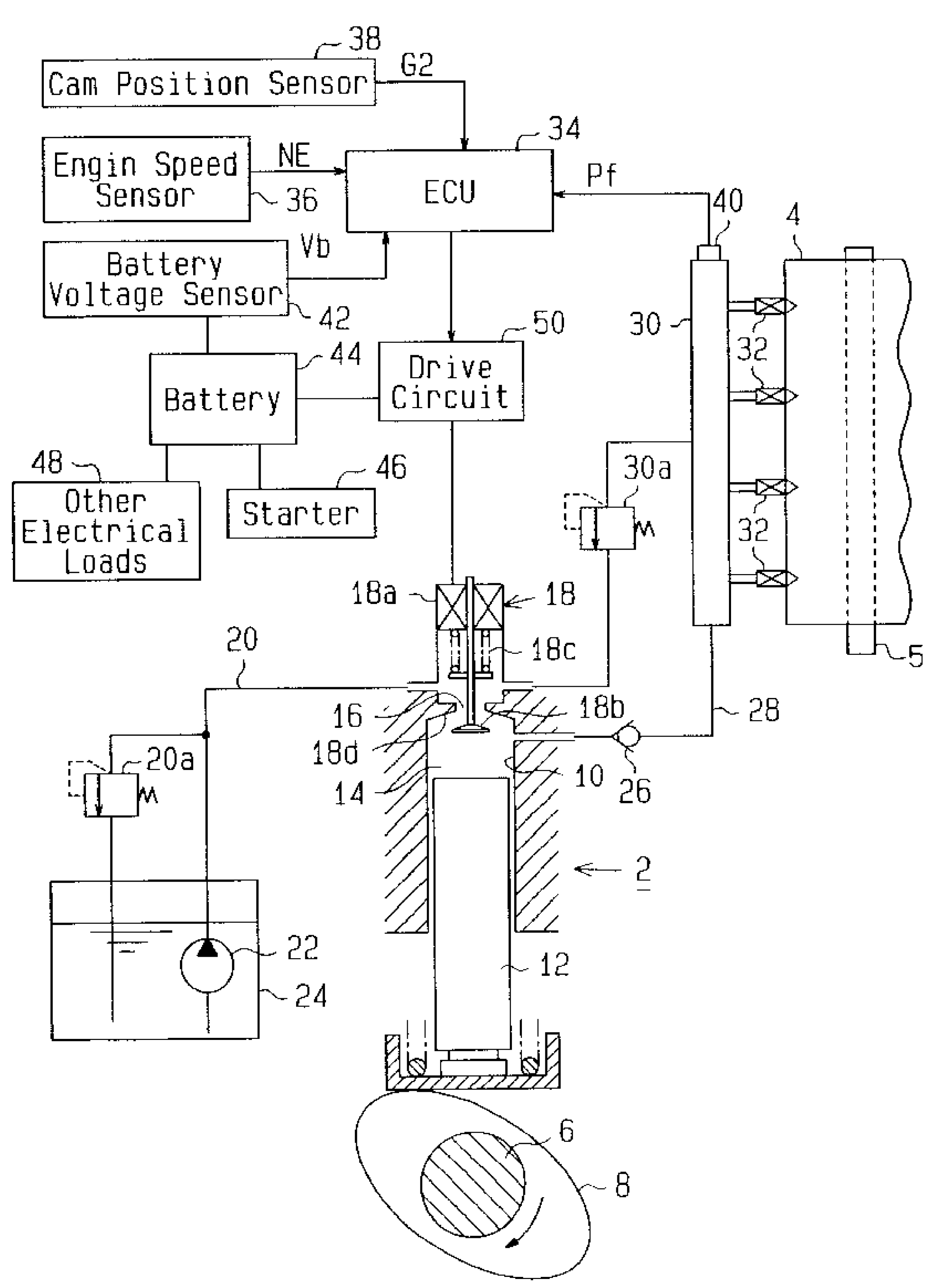
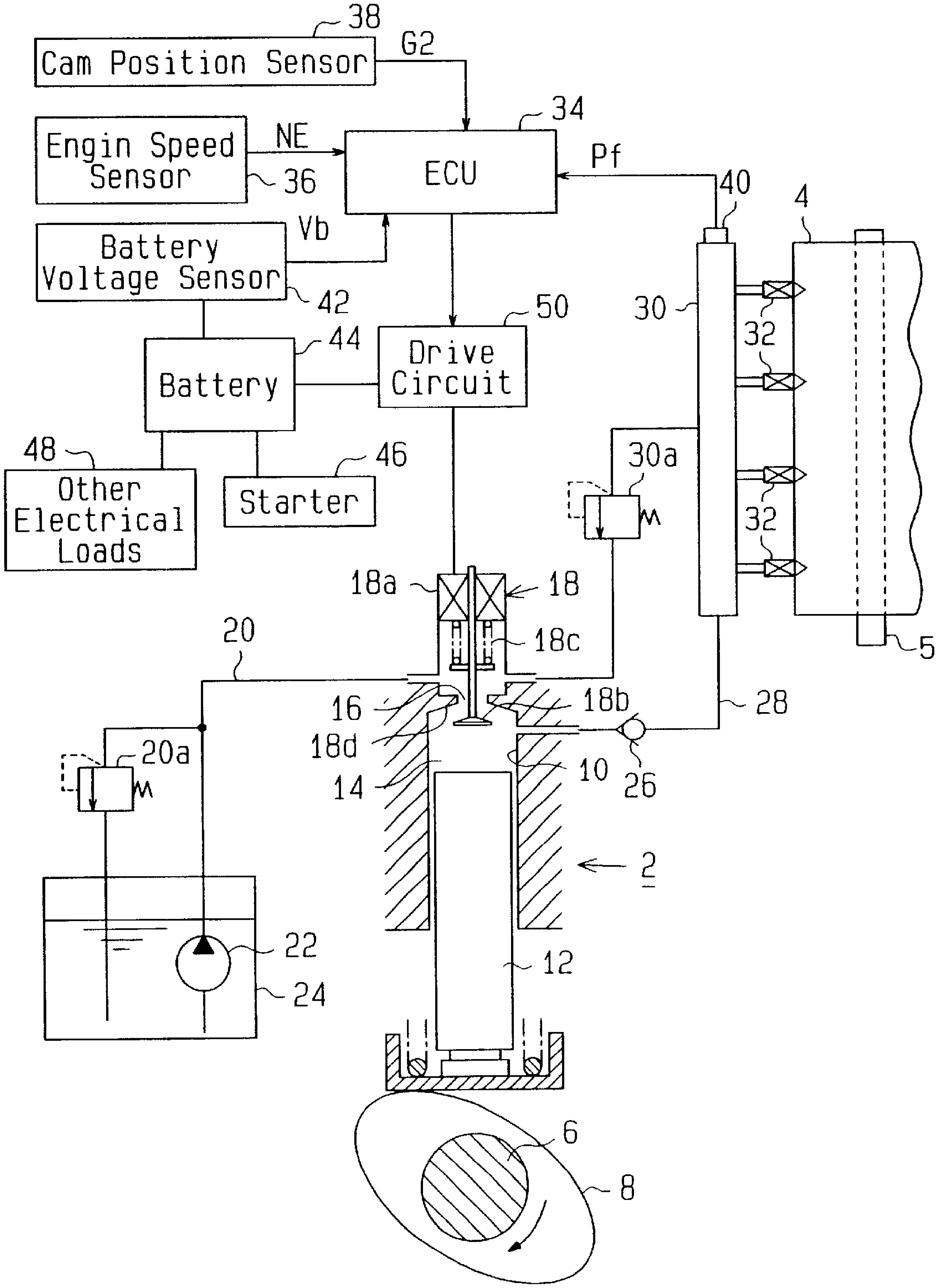


Fig.1



Cam Position Sensor
38
G2
34
Engin Speed Sensor
NE
36
ECU
Pf
40
4
Battery Voltage Sensor
Vb
42
50
30
44
Battery
Drive Circuit
32
48
46
30a
Other Electrical Loads
Starter
32
18a
18
20
18c
5
16
18b
28
18d
14
10
26
20a
2
22
24
12
6
8

Fig.2(A)

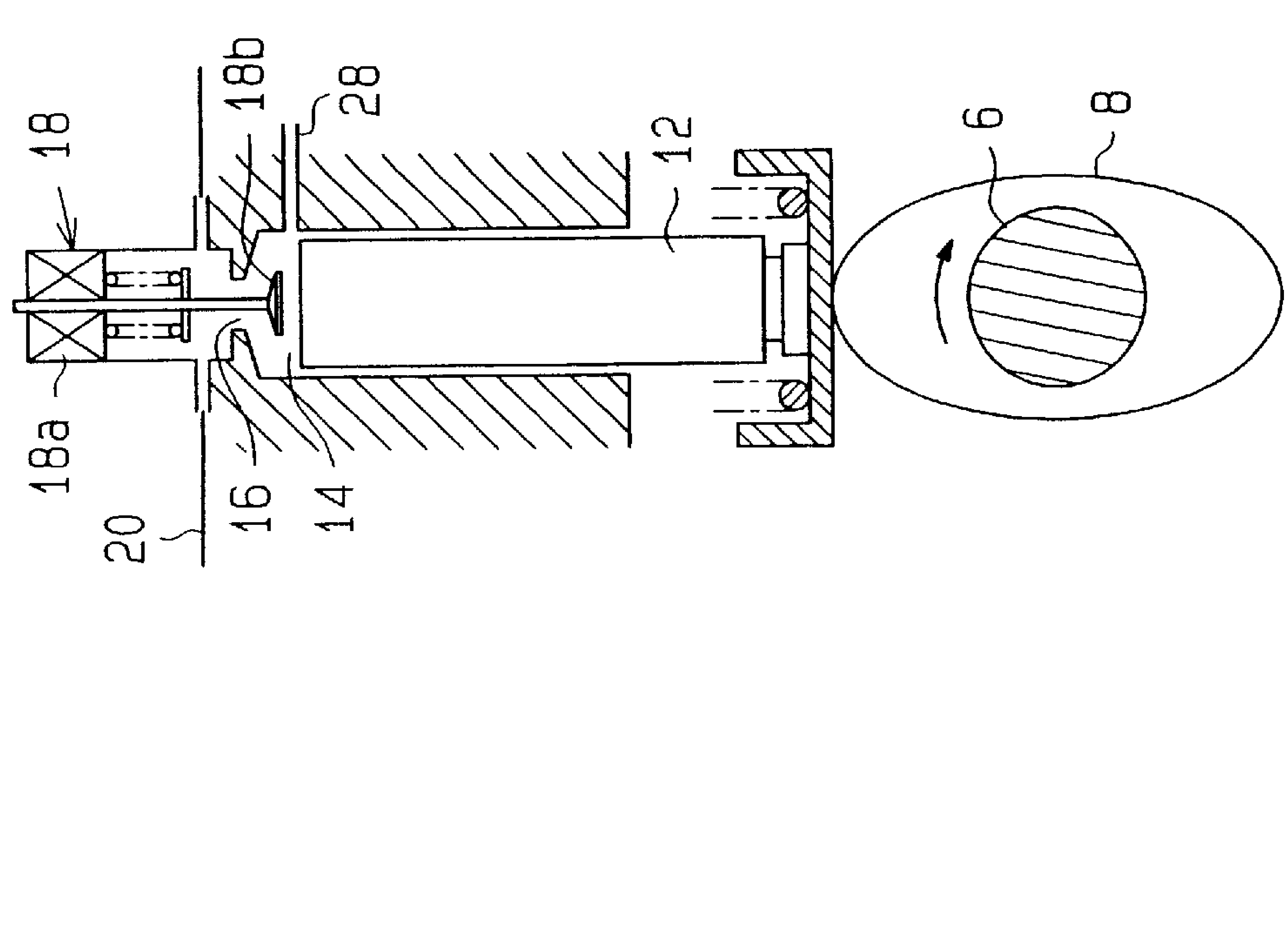


Fig.2(B)

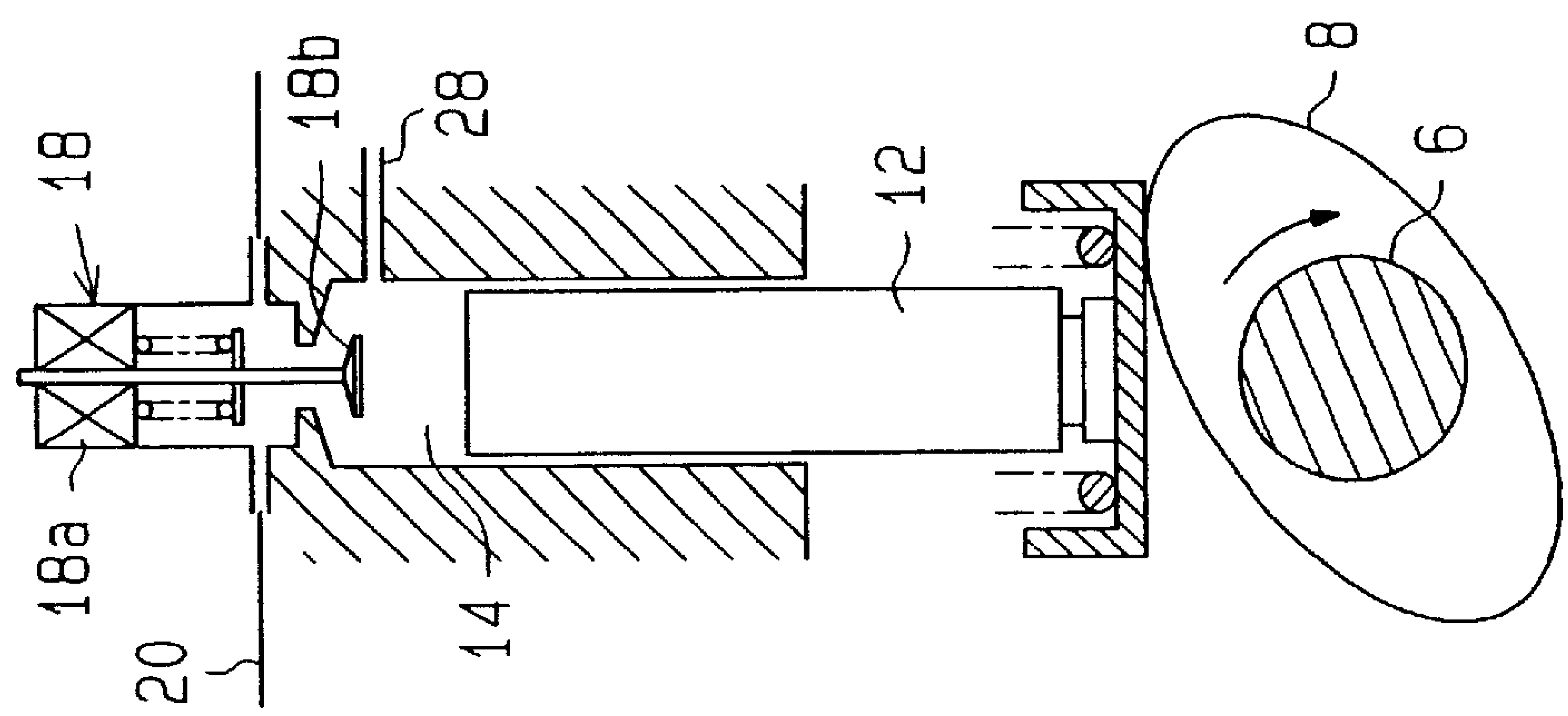


Fig.2(C)

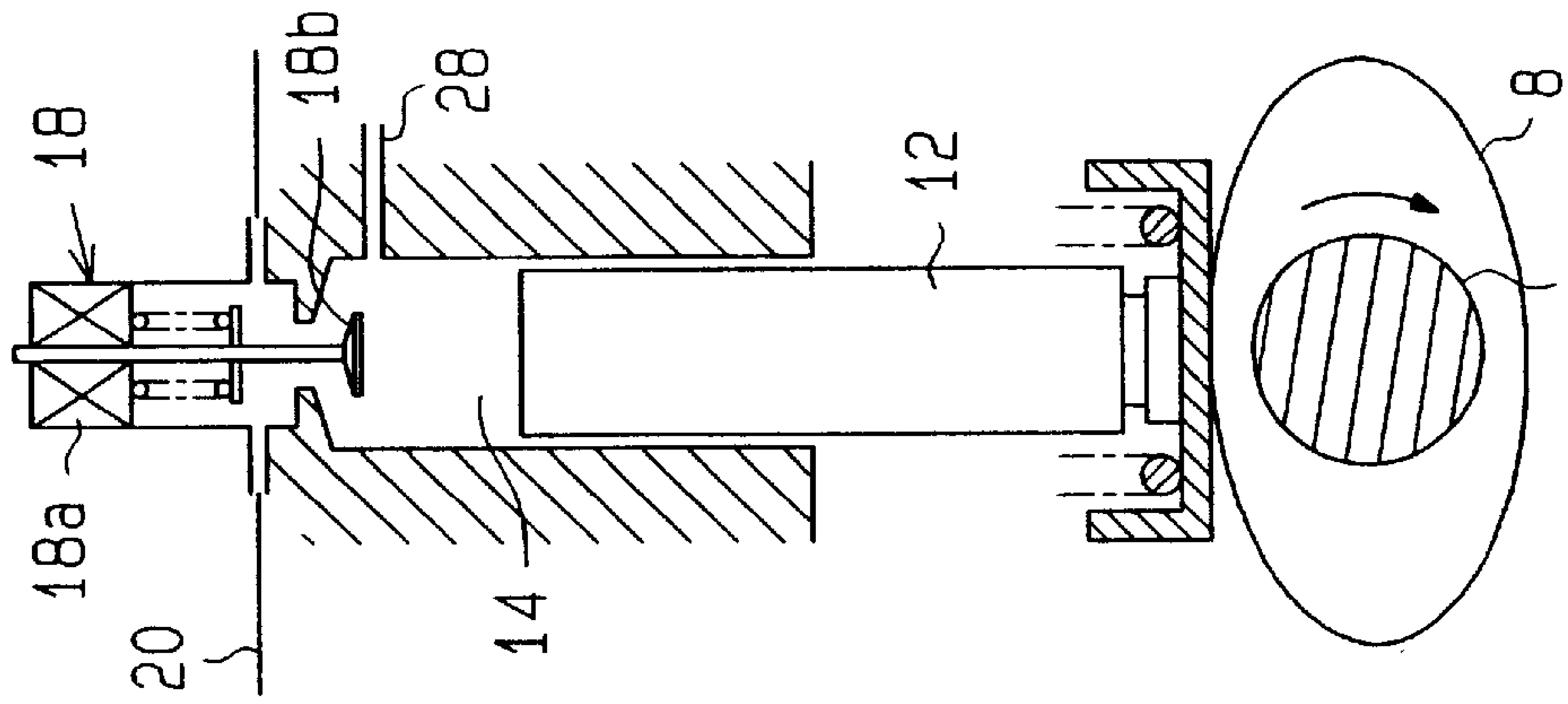


Fig.3(A)

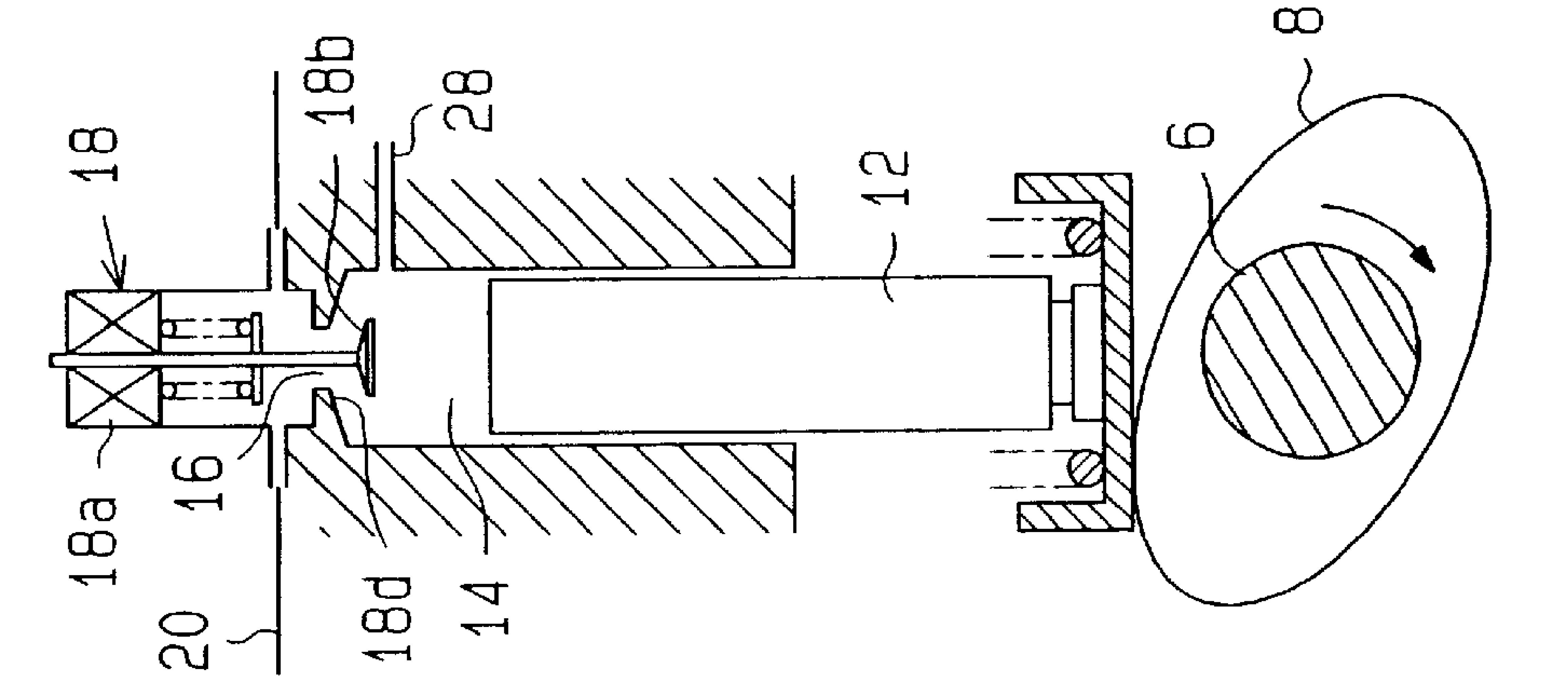


Fig.3(B)

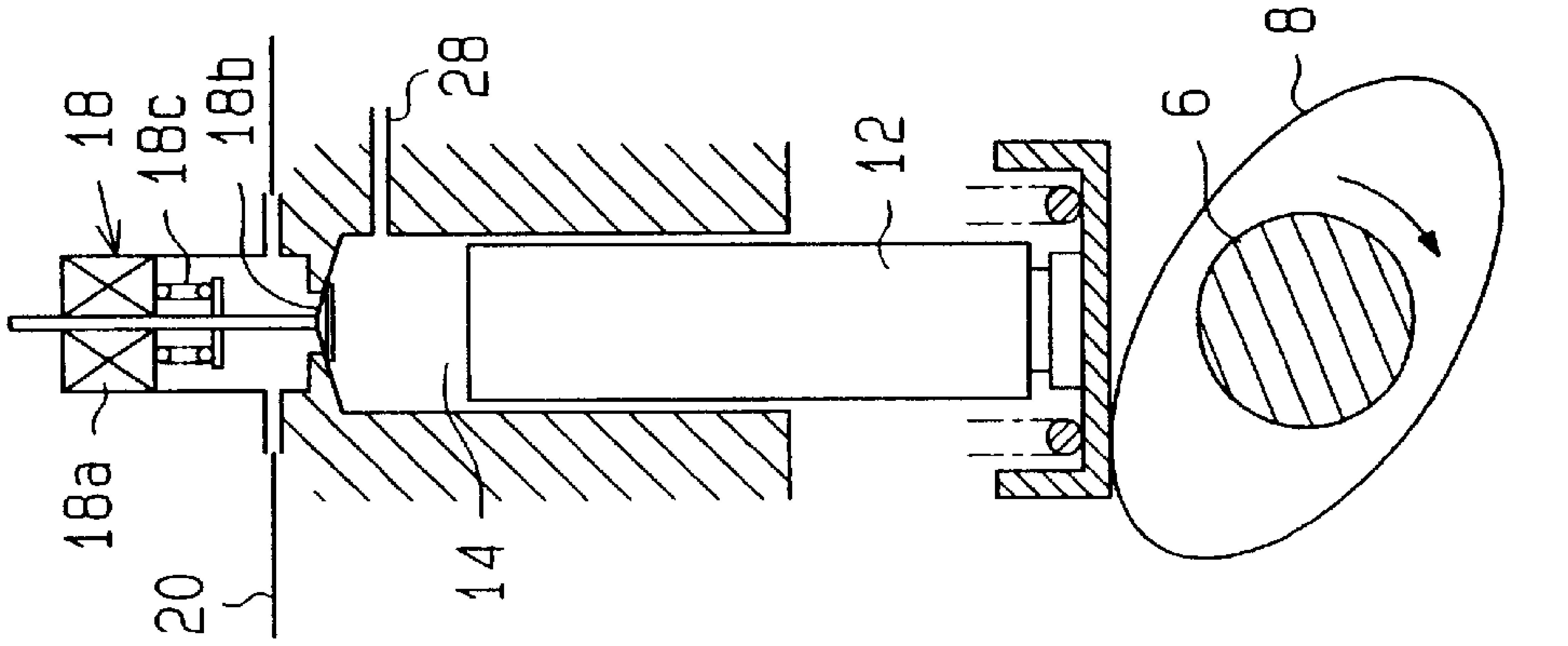


Fig.3(C)

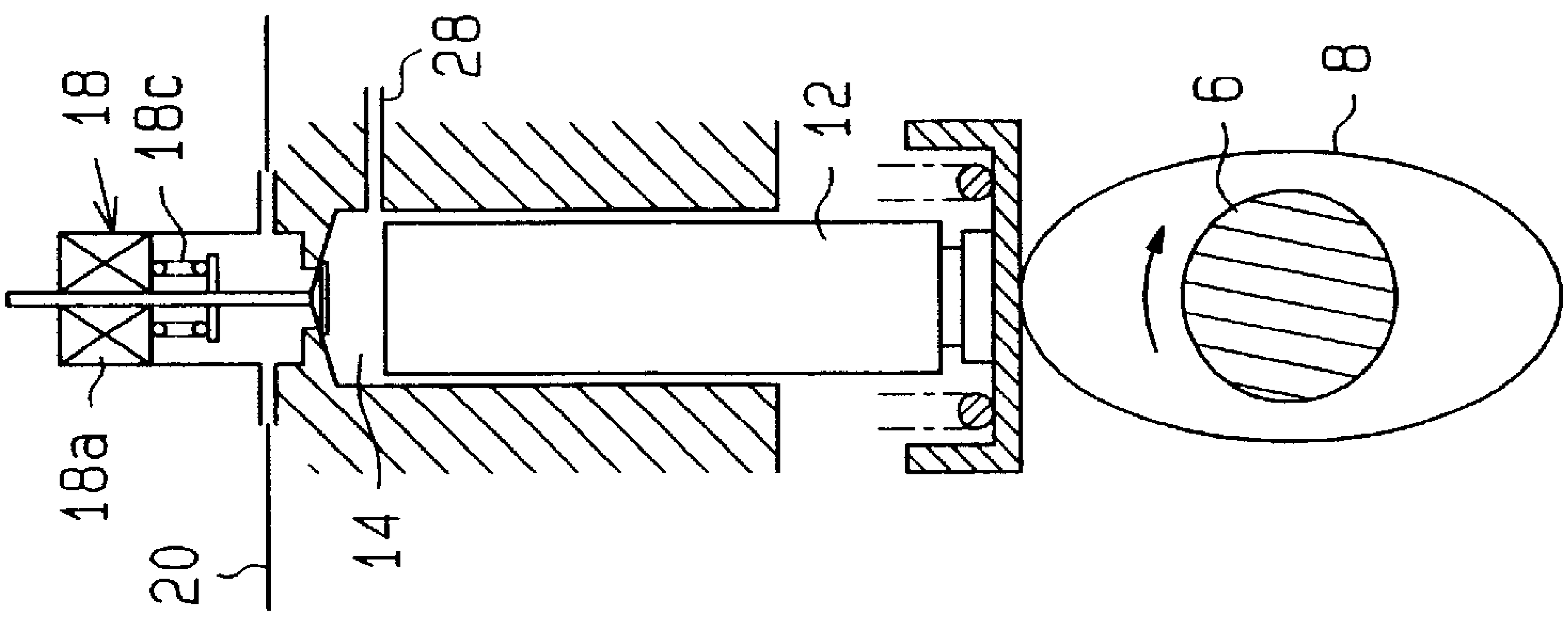


Fig. 4

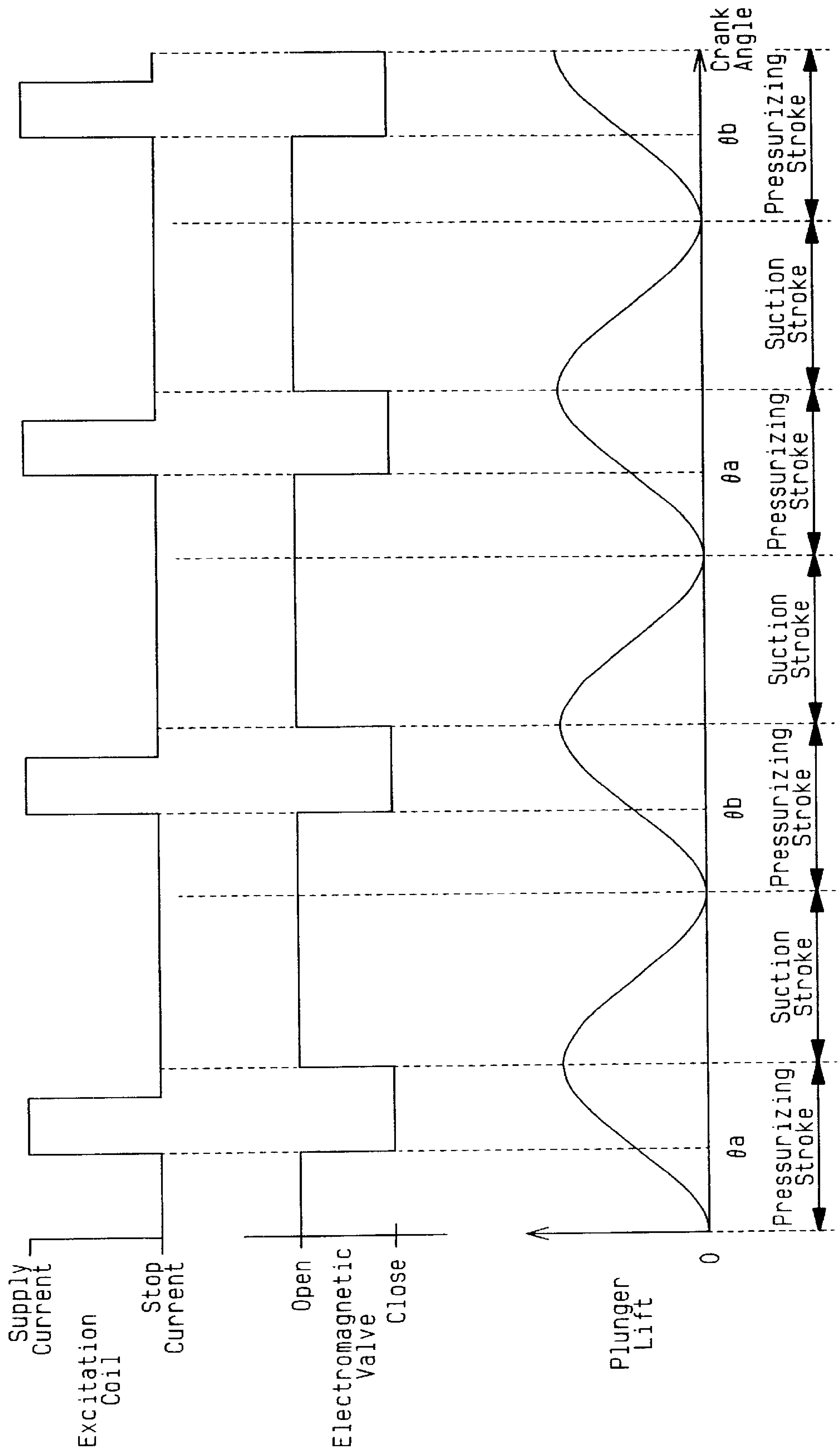

Supply Current
Excitation Coil
Stop Current
Open
Electromagnetic Valve
Close
Plunger Lift
0
Crank Angle
θa
θb
θa
θb
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke

Fig.5

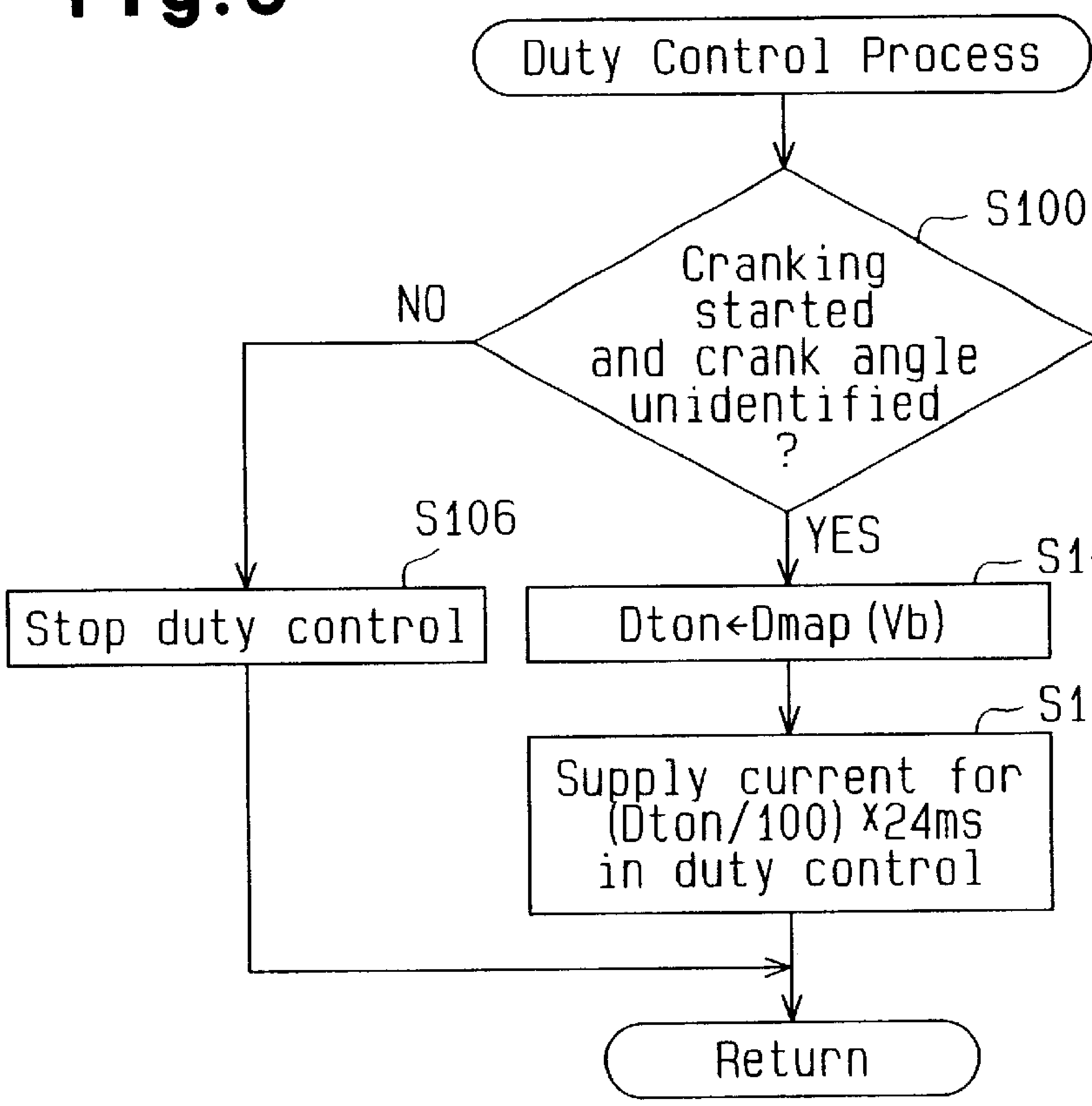
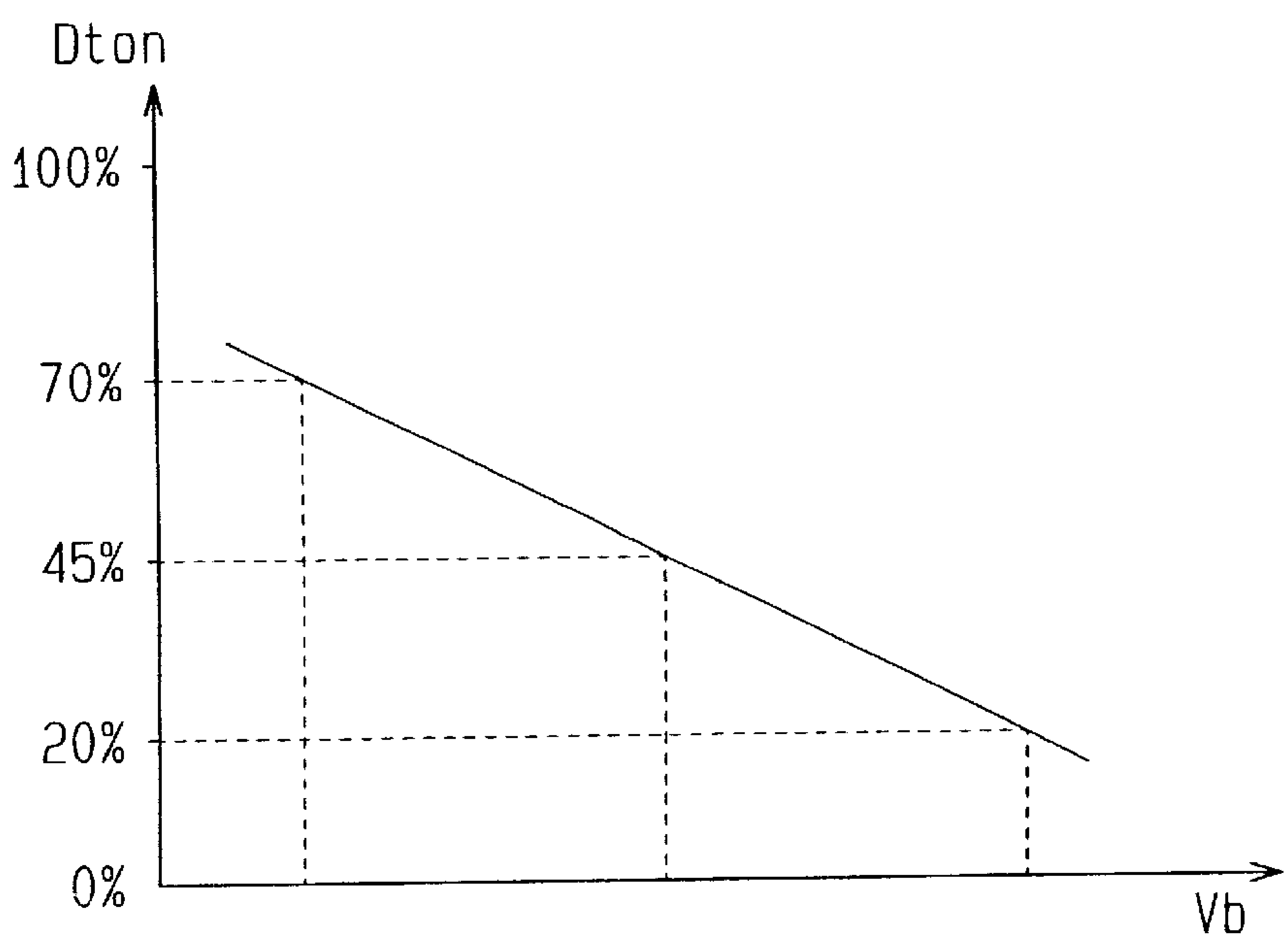

Duty Control Process
S100
Cranking started and crank angle unidentified ?
NO
YES
S106
Stop duty control
S102
Dton←Dmap (Vb)
S104
Supply current for (Dton/100) ×24ms in duty control
Return

Fig.6


Dton
100%
70%
45%
20%
0%
Vb

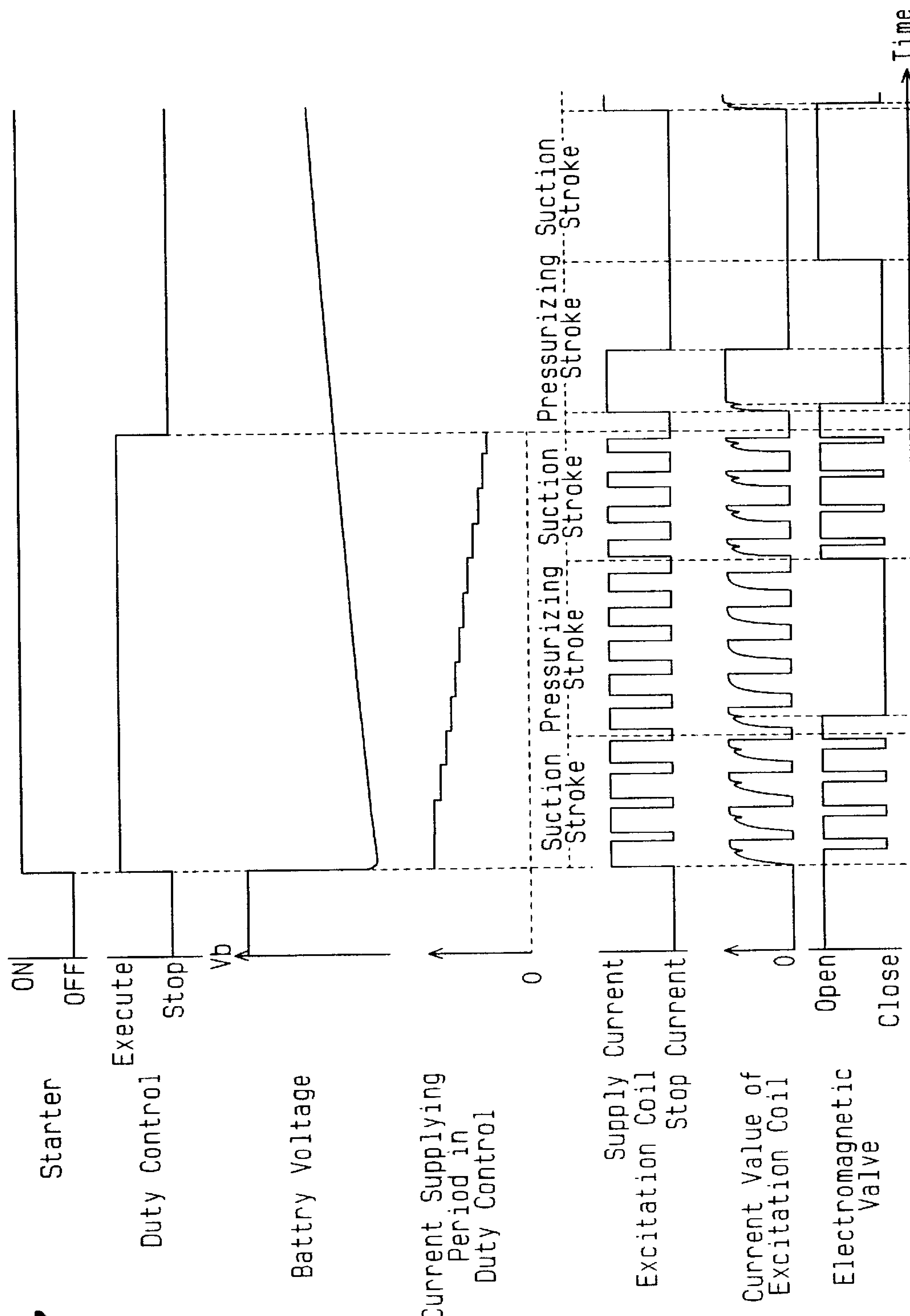

Starter
ON
OFF
Duty Control
Execute
Stop
Battry Voltage
Vb
Current Supplying Period in Duty Control
0
Excitation Coil
Supply Current
Stop Current
Current Value of Excitation Coil
0
Electromagnetic Valve
Open
Close
Suction Stroke
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke
Suction Stroke
t0
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10
Time

Fig.7

Fig.8

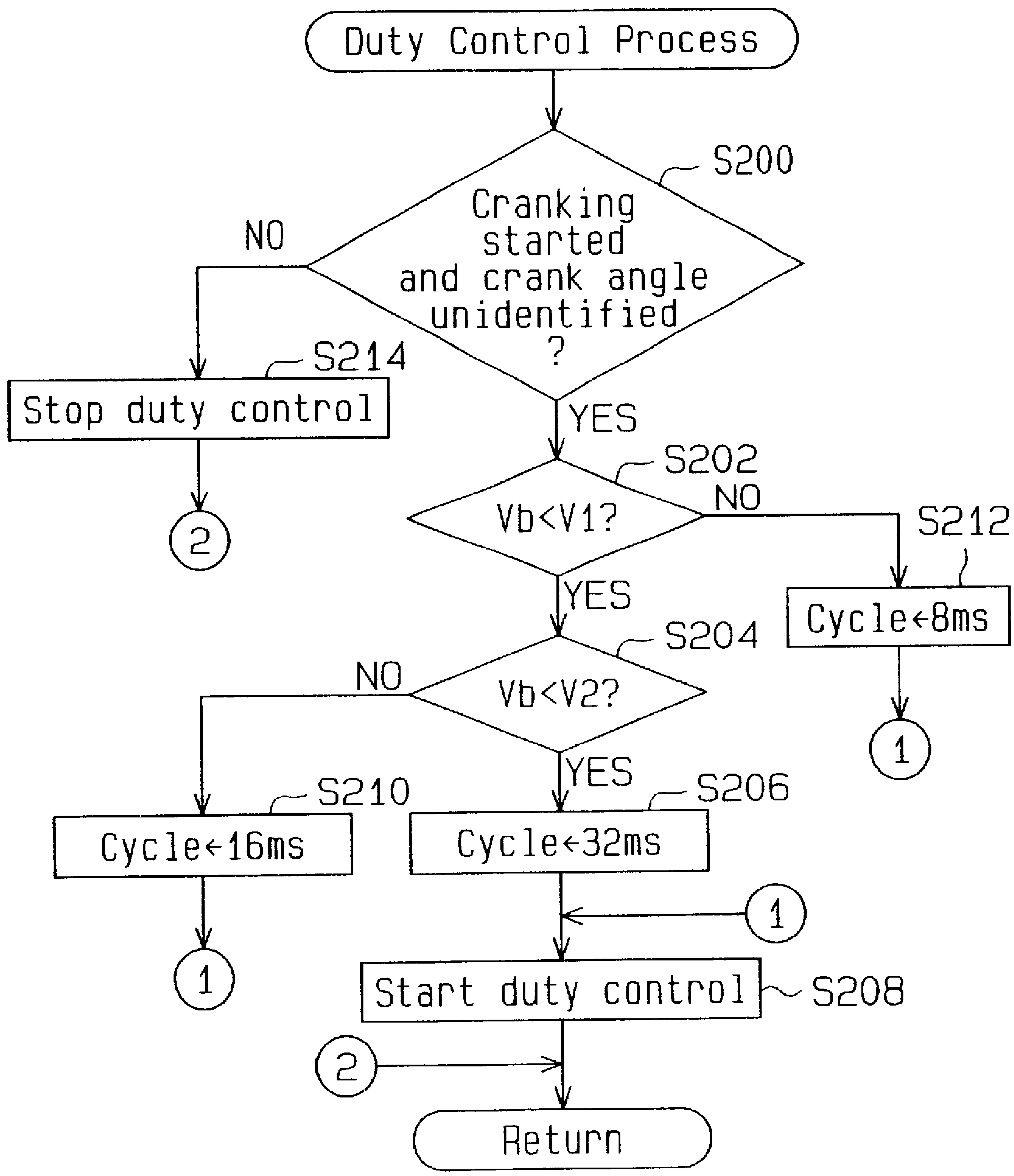

Duty Control Process
Cranking started and crank angle unidentified ?
S200
NO
YES
S214
Stop duty control
2
Vb<V1?
S202
NO
S212
Cycle←8ms
1
YES
Vb<V2?
S204
NO
YES
S210
Cycle←16ms
1
S206
Cycle←32ms
1
Start duty control
S208
2
Return

Fig.9

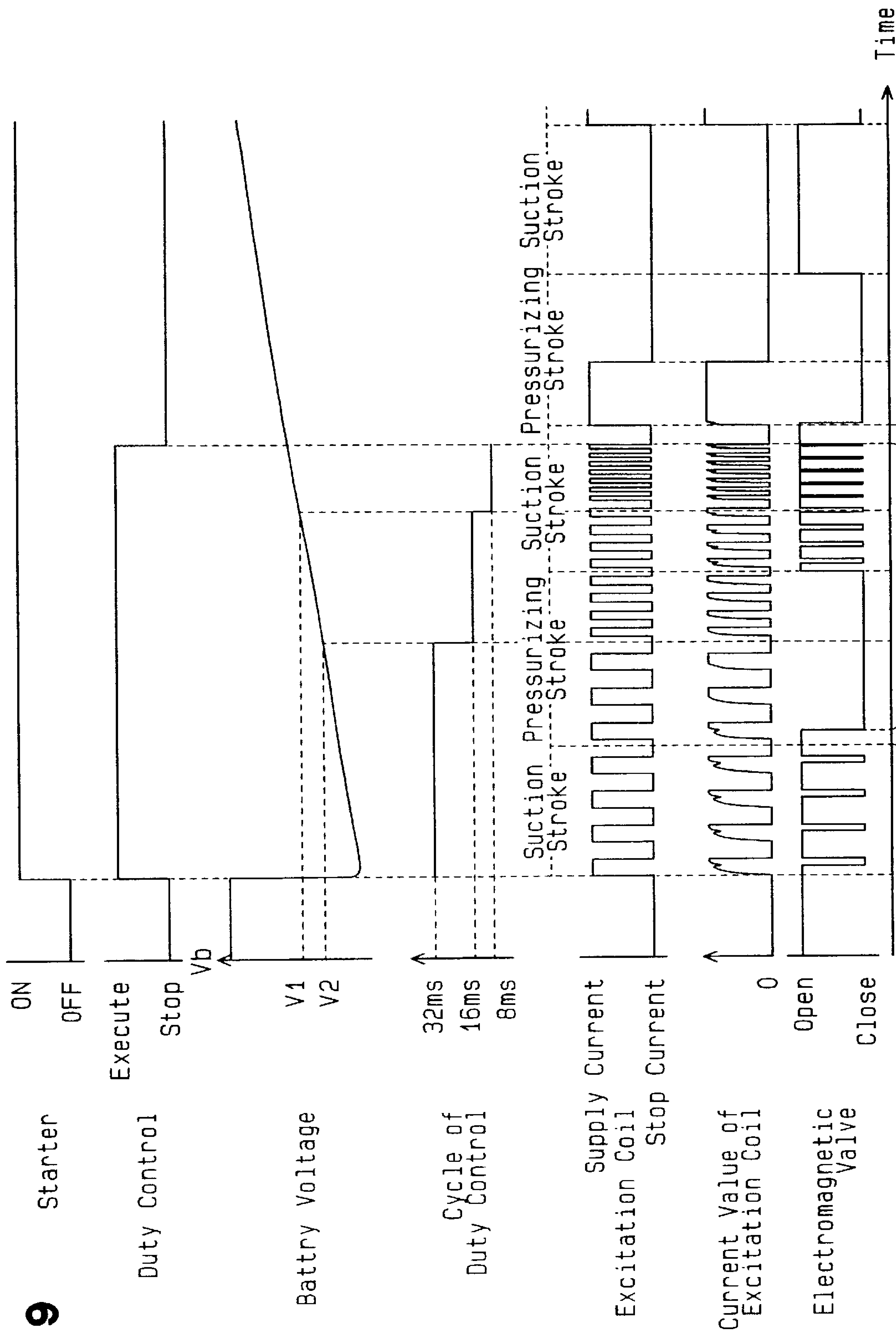

Starter
ON
OFF
Duty Control
Execute
Stop
Battry Voltage
Vb
V1
V2
Cycle of Duty Control
32ms
16ms
8ms
Excitation Coil
Supply Current
Stop Current
Current Value of Excitation Coil
0
Electromagnetic Valve
Open
Close
Suction Stroke
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke
Suction Stroke
t20
t21
t22
t23
t24
t25
t26
t27
t28
t29
t30
Time

Fig.10

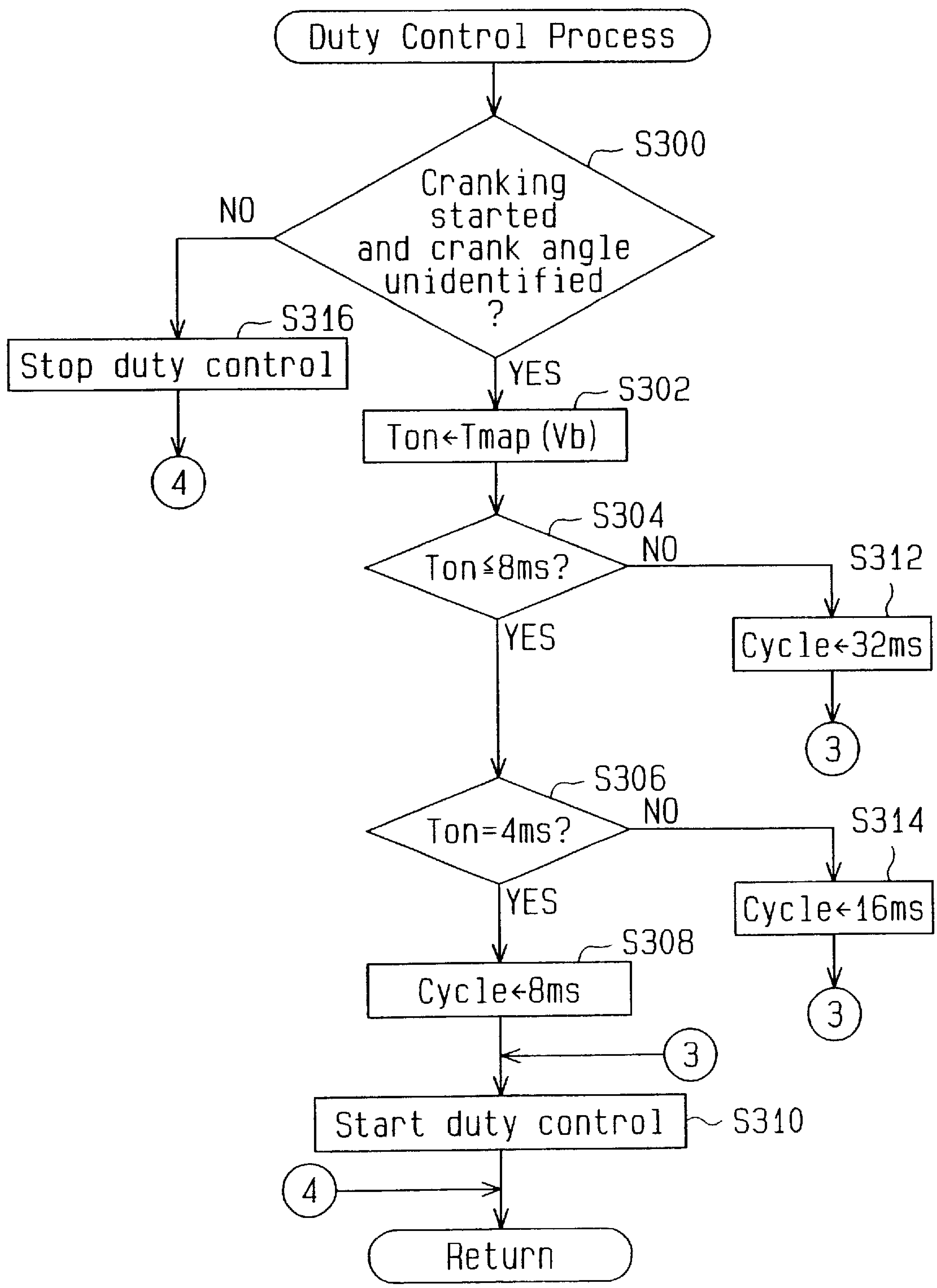

Duty Control Process
Cranking started and crank angle unidentified ?
S300
NO
YES
S316
Stop duty control
4
S302
Ton←Tmap (Vb)
S304
Ton≦8ms?
NO
YES
S312
Cycle←32ms
3
S306
Ton=4ms?
NO
YES
S314
Cycle←16ms
3
S308
Cycle←8ms
3
Start duty control
S310
4
Return

Fig.11

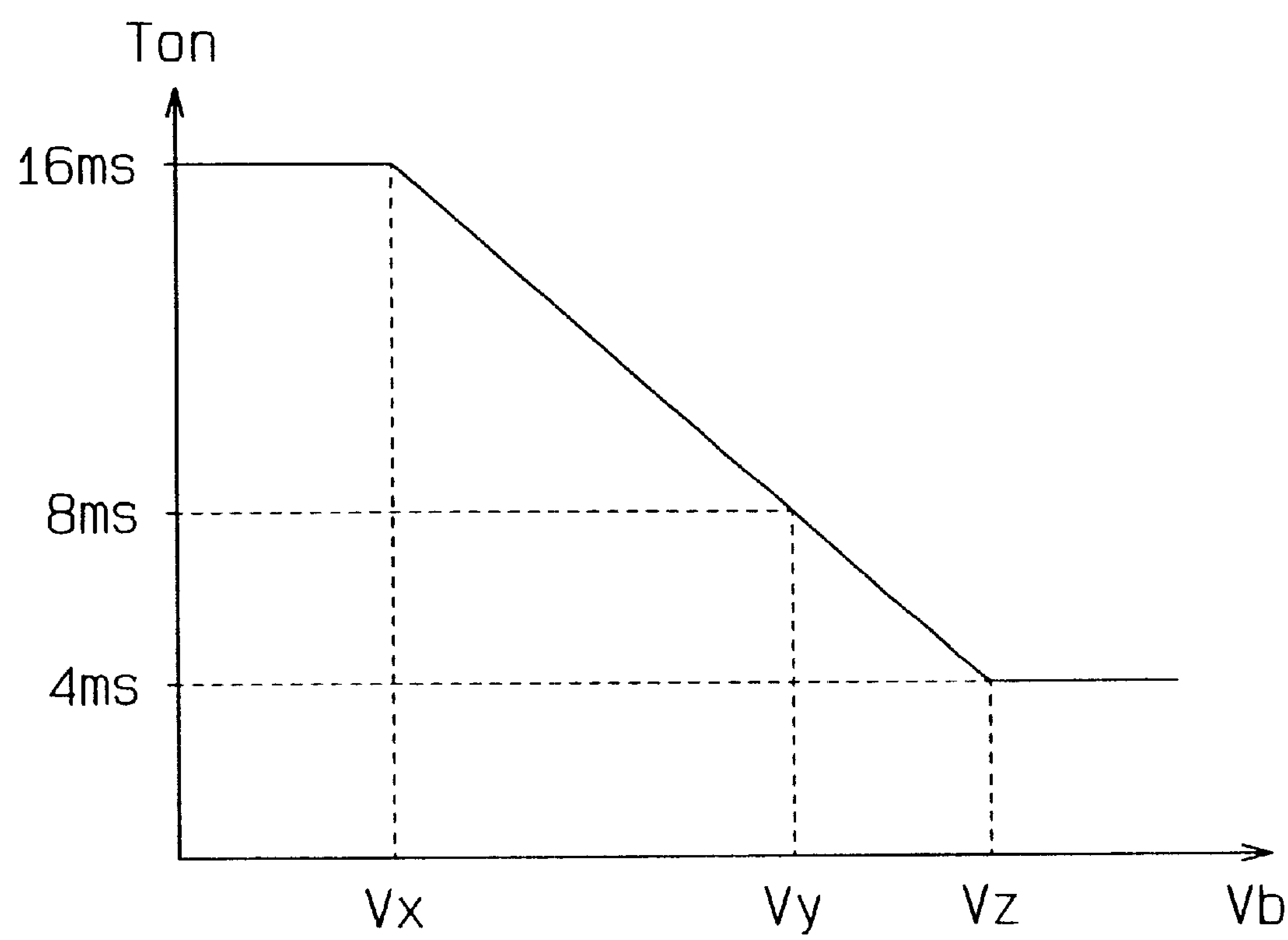
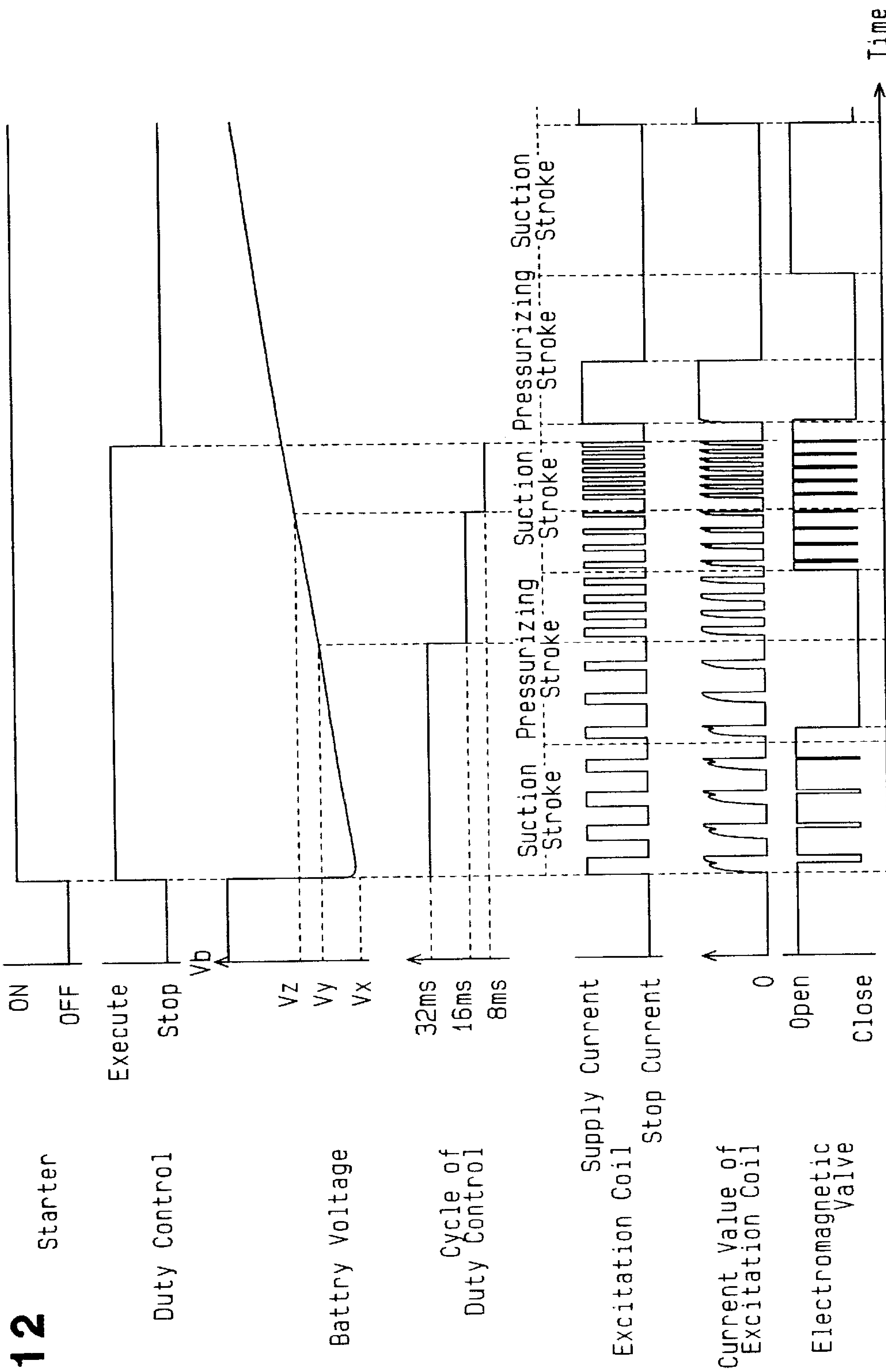
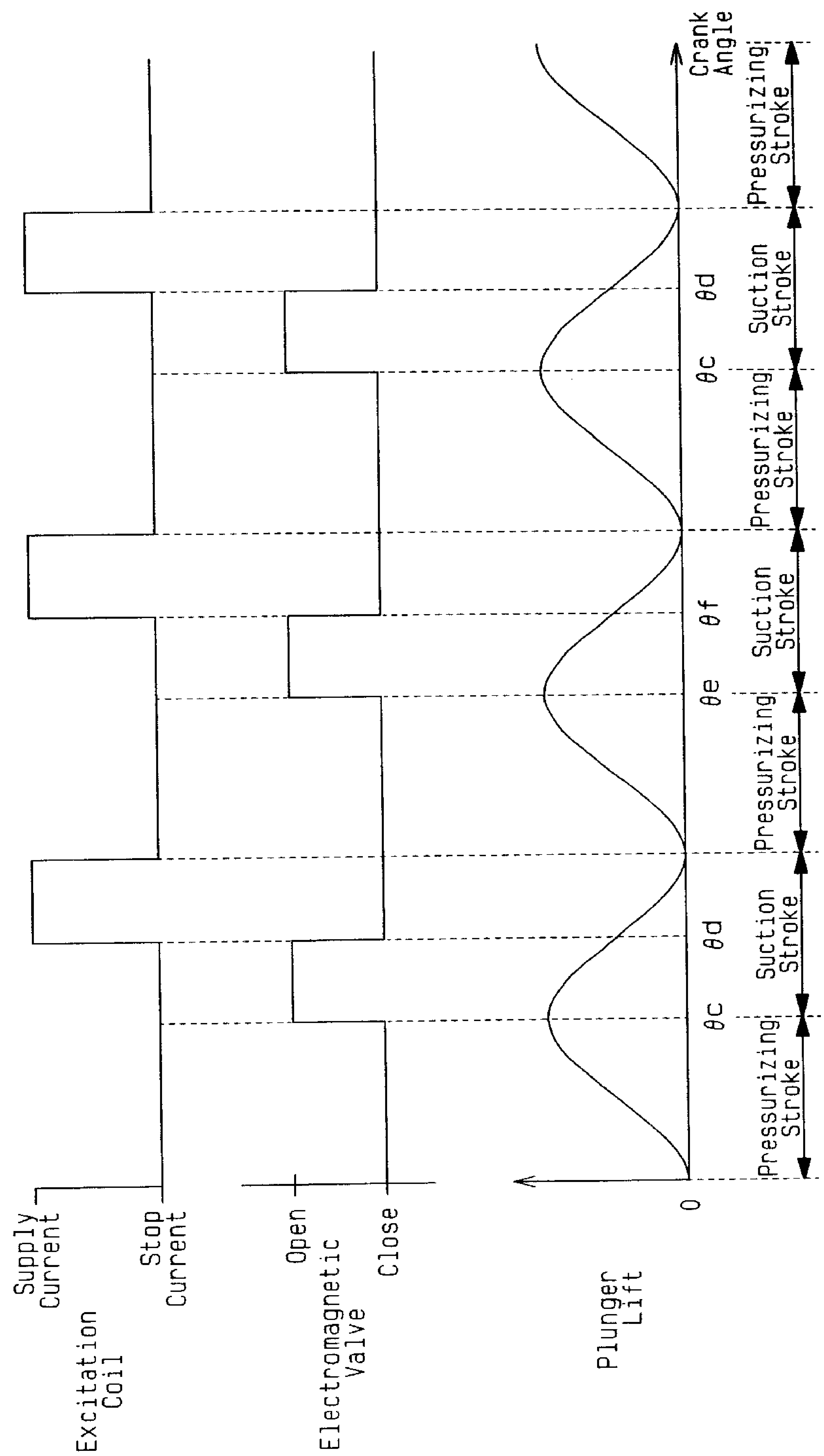


Fig.12



Starter
ON
OFF
Duty Control
Execute
Stop
Battry Voltage
Vb
Vz
Vy
Vx
Cycle of Duty Control
32ms
16ms
8ms
Excitation Coil
Supply Current
Stop Current
Current Value of Excitation Coil
0
Electromagnetic Valve
Open
Close
Suction Stroke
Pressurizing Stroke
Suction Stroke
Pressurizing Stroke
Suction Stroke
Time
t40
t41
t42
t43
t44
t45
t46
t47
t48
t49
t50

Fig.13


Supply Current
Stop Current
Excitation Coil
Open
Close
Electromagnetic Valve
Plunger Lift
0
Crank Angle
θc
θd
θe
θf
Pressurizing Stroke
Suction Stroke

HIGH PRESSURE FUEL SUPPLYING APPARATUS FOR INTERNAL COMBUSTION ENGINE AND METHOD FOR CONTROLLING THE APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to an high pressure fuel supplying apparatus for in an internal combustion engine, which apparatus sends high pressure fuel to a fuel injection system of the engine, and to a method for controlling the apparatus.

Japanese Laid-Open Patent Publication No. 10-61468 discloses a high pressure fuel pump having a plunger that is reciprocated by rotation of a crankshaft of an engine. Reciprocation of the plunger in a pressurizing chamber draws fuel into the pressurizing chamber and pressurizes the drawn fuel. The pressurized fuel is sent to a delivery pipe.

During a suction stroke of the plunger, in which the pressurizing chamber is expanded, an electromagnetic valve located in the pressurizing chamber is supplied with no current and is thus opened. As a result, fuel is supplied to the interior of the pressurizing chamber from a feed pump, which forms part of a fuel supply source. During a pressurizing stroke of the plunger, in which the pressurizing chamber is compressed, the electromagnetic valve is supplied with current and closed at a time corresponding to the amount of fuel that is to be sent to the fuel injection system. As a result, fuel in the pressurizing chamber is pressurized. The pressurized fuel pushes open a fuel discharge valve and is supplied to the delivery pipe, which forms part of a fuel injection system.

The plunger of the aforementioned publication is reciprocated by rotation of the crankshaft of the internal combustion engine. Therefore, in order to determine the stroke position of the plunger in the pressurizing chamber, the rotational phase angle of the crankshaft must be identified. However, the rotational phase angle of the crankshaft cannot be identified, for example, when the engine is being cranked. At this time, it is impossible to control the electromagnetic valve according to a normal process even if the high pressure pump is operating. Thus, when the engine is being cranked, high pressure fuel is not supplied to the fuel injection system, and fuel in the fuel injection system is not pressurized at an early stage. This hinders a desirable fuel injection and degrades the starting of the engine.

To eliminate this drawback, the technology disclosed in the above publication pressurizes fuel in the fuel injection system at an early stage in the following manner. That is, when the rotation phase angle of the crankshaft is not identified, a duty control is performed to supply and stop current to the electromagnetic valve in short cycles. Each suction stroke of the plunger corresponds to each current stopping period of the duty control. In each current stopping period, the electromagnetic valve is opened, and fuel is drawn into the pressurizing chamber. When the plunger is at a pressurizing stroke, the electromagnetic valve is closed at a first current supplying timing in the duty control. During this closing period of the electromagnetic valve, the pressure of the fuel in the pressurizing chamber increases. Although current to the electromagnetic valve is stopped after the closing period, the pressure of the fuel in the pressurizing chamber maintains the closed state of the electromagnetic valve. In the subsequent pressurizing strokes, the electromagnetic valve is not opened regardless of whether the duty control is performed. Therefore, even if the rotational phase

angle of the crankshaft is not identified, the pressure of the fuel in the pressurizing chamber is increased, so that the fuel pushes open the fuel discharging valve and is supplied to the fuel injection system in a pressurized state.

However, when the engine is being cranked, the voltage of a power supply, such as a battery, is lowered due to an electrical load created by activation of a starter motor. If the voltage is significantly lowered, the electromagnetic valve is not completely closed during the current supplying period in the duty control, which results in an insufficient pressure increase in the pressurizing chamber. This possibly hinders the fuel injection system from receiving high pressure fuel, and prevents the pressurizing efficiency of fuel supplied to the fuel injection system from being improved.

SUMMARY OF THE INVENTION

Accordingly, it is an objective of the present invention to provide a high pressure fuel supplying apparatus for an internal combustion engine and a method for controlling the apparatus, which apparatus and method improve the pressurizing efficiency of fuel supplied to a fuel injection system.

To achieve the foregoing and other objectives and in accordance with the purpose of the present invention, a high pressure fuel supplying apparatus is provided. The apparatus pressurizes fuel supplied from a fuel supply source and sends the pressurized fuel to a fuel injection system of an internal combustion engine. The apparatus includes a fuel pump, an electromagnetic valve, a voltage detecting device, and a controller. The fuel pump has a pressurizing chamber, and repeats a pressurizing stroke and a suction stroke in accordance with rotation of the engine. During each suction stroke, the fuel pump draws fuel from the fuel supply source to the pressurizing chamber. During each pressurizing stroke, the fuel pump pressurizes fuel in the pressurizing chamber and sends the pressurized fuel to the fuel injection system. The electromagnetic valve selectively connects and disconnects the pressurizing chamber with the fuel supply source. The electromagnetic valve is actuated by electricity supplied from a power supply. The voltage detecting device detects a voltage of the power supply. The controller controls the electromagnetic valve. To adjust an amount of fuel to be supplied to the fuel injection system, the controller determines opening and closing timing of the electromagnetic valve based on a rotational phase of the engine. When the rotational phase of the engine is not identified, the controller executes a duty control to cyclically repeats supplying and stopping of current to the electromagnetic valve. The controller extends a current supplying period in each cycle of the duty control as the voltage detected by the voltage detecting device is lowered.

In another aspect of the present invention, a method for controlling a high pressure fuel supplying apparatus for an internal combustion engine is provided. The apparatus includes a fuel pump having a pressurizing chamber and an electromagnetic valve. The fuel pump repeats a pressurizing stroke and a suction stroke in accordance with rotation of the engine. During each suction stroke, the fuel pump draws fuel from a fuel supply source to the pressurizing chamber. During each pressurizing stroke, the fuel pump pressurizes fuel in the pressurizing chamber and sends the pressurized fuel to a fuel injection system of the engine. The electromagnetic valve is actuated by electricity supplied from a power supply to selectively connect and disconnect the pressurizing chamber with the fuel supply source. The method includes: determining opening and closing timing of the electromagnetic valve based on a rotational phase of the engine, thereby adjusting an amount of fuel to be supplied to the fuel injection system; executing a duty control to cyclically repeats supplying and stopping of current to the electromagnetic valve when the rotational phase of the engine is not identified; and extending a current supplying period in each cycle of the duty control as the voltage of the power supply is lowered.

Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

FIG. **1** is a diagrammatic view illustrating a high pressure fuel pump, an engine, and a control system according to a first embodiment;

FIGS. **2**(A) to **2**(C) are cross-sectional views showing a suction stroke of the high pressure fuel pump of FIG. **1** after the crank angle is identified;

FIGS. **3**(A) to **3**(C) are cross-sectional views showing a pressurizing stroke of the high pressure fuel pump of FIG. **1** after the crank angle is identified;

FIG. **4** is a crank angle chart showing an operation of the high pressure pump of FIG. **1** after the crank angle is identified;

FIG. **5** is a flowchart showing a duty control process executed when the engine is being cranked;

FIG. **6** is a graph showing a duty map Dmap used in the duty control process of FIG. **5**;

FIG. **7** is a timing chart showing an example of a control of the high pressure fuel pump shown in FIG. **1**;

FIG. **8** is a flowchart showing a duty control process according to a second embodiment of the present invention, which process is executed when the engine is being cranked;

FIG. **9** is a timing chart showing an example of a control of a high pressure fuel pump according to the second embodiment;

FIG. **10** is a flowchart showing a duty control process according to a third embodiment of the present invention, which process is executed when the engine is being cranked;

FIG. **11** is a graph showing a current supplying period map Tmap used in the duty control process of FIG. **10**;

FIG. **12** is a timing chart showing an example of a control of the high pressure pump according to the third embodiment; and

FIG. **13** is a crank angle chart showing an operation of a high pressure fuel pump according to another embodiment after the crank angle is identified.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the present invention will now be described with reference to FIGS. **1** to **7**.

FIG. **1** shows a high pressure fuel pump **2**, an internal combustion engine, and a control system for controlling the pump **2** and the engine. In this embodiment, the internal combustion engine is a cylinder injection type gasoline engine **4**.

The engine **4** has engine cylinders (not shown), fuel injection valves **32**, a crankshaft **5**. A combustion chamber is defined in each engine cylinder, and each fuel injection valve **32** corresponds to one of the engine cylinders. A delivery pipe **30** is connected to the fuel injection valves **32**. The fuel injection valves **32** and the delivery pipe **30** form a fuel injection system. A piston (not shown) reciprocates in each engine cylinder. Accordingly, the crankshaft **5** rotates.

The high pressure fuel pump **2** includes a camshaft **6** interlocked with the crankshaft **5**, a cam **8** located on the camshaft **6**, a cylinder **10**, and a plunger **12**. The plunger **12** is reciprocated by the cam **8**. The cylinder **10** and the plunger **12** define a pressurizing chamber **14**. The high pressure fuel pump **2** further includes an electromagnetic valve **18**. The electromagnetic valve **18** is arranged to correspond to a fuel inlet **16** that opens to the pressurizing chamber **14**.

Fuel is pumped out of a fuel tank **24** by a feed pump **22**. The fuel tank **24** and the feed pump **22** form a fuel supply source. Fuel is then drawn in to the pressurizing chamber **14** through a low pressure fuel passage **20** and the fuel inlet **16** during a suction stroke of the high pressure fuel pump **2**, or during a suction stroke of the plunger **12**. Some of the fuel that is pumped out by the feed pump **22** is not sent to the high pressure fuel pump **2**. Such fuel or fuel that is returned to the low pressure fuel passage **20** from the high pressure fuel pump **2** are returned to the fuel tank **24** through a relief valve **20***a*.

During a pressurizing stroke of the high pressure fuel pump **2**, or during a pressurizing stroke of the plunger **12**, high pressure fuel that is pressurized in the pressurizing chamber **14** pushes open a check valve **26** and is sent to the delivery pipe **30** through a high pressure fuel passage **28**. As a result, high pressure fuel is pressurized to a level that enables the fuel to be injected into the combustion chambers of the engine cylinders at a compression stroke. The fuel is then supplied to each fuel injection valve **32**. If there is surplus fuel that is not subjected to injection in the delivery pipe **30**, the surplus fuel is returned to a low pressure fuel passage **20** through the relief valve **30***a*.

An electronic control unit (ECU) **34** controls the electromagnetic valve **18** to adjust the amount of high pressure fuel supplied from the high pressure fuel pump **2** to the delivery pipe **30**. The ECU **34** is a controller that has an electronic circuit including a digital computer. The ECU **34** receives detection signals from an engine speed sensor **36**, a cam position sensor **38**, a fuel pressure sensor **40**, a battery voltage sensor **42**, and other sensors and switches. The engine speed sensor **36** is provided at the crankshaft **5**, and outputs a pulse signal NE every time the crankshaft **5** rotates by 30°. The rotational phase angle of the crankshaft **5** (the rotational phase of the engine **4**) is referred to as a crank angle. A range of the crank angle from a predetermined reference angle, or 0°, to 720° is referred to one cycle. That is, a rotational angle corresponding to two turns of the crankshaft **5** is referred to as one cycle. The cam position sensor **38** is provided at the camshaft **6**, which rotates one turn while the crankshaft **5** rotates two turns. The cam position sensor **38** outputs a reference crank angle signal G2 at a timing when the crank angle is the reference crank angle (the reference rotational phase of the engine **4**). The engine speed sensor **36** and the cam position sensor **38** function as a device for detecting the rotational phase of the engine **4**. The fuel pressure sensor **40** is provided at the delivery pipe **30** and outputs a signal that represents the fuel pressure in the delivery pipe **30**, or a pressure Pf of fuel supplied to the fuel injection valves **32**. The battery voltage sensor **42**, which functions as a voltage detecting device, detects a voltage Vb of a battery **44** and outputs a signal corresponding to the voltage Vb. The battery **44** is a power supply of the electromagnetic valve **18**, an engine starter **46**, and other electrical loads **48**.

The ECU **34** performs computations based on inputted signals to control a drive circuit **50**, thereby supplying and stopping a current from the battery **44** to the electromagnetic valve **18**. The ECU **34** also performs other engine controls including a fuel injection control and an ignition timing control.

The ECU **34** identifies a reference crank angle based on the reference crank angle signal G2 from the cam position sensor **38**. Using the reference crank angle as a starting point, the ECU **34** identifies the current crank angle based on the pulse signal NE from the engine speed sensor **36**. Therefore, while the engine **4** is being cranked, the ECU **34** cannot identify the crank angle until receiving the first reference crank angle signal G2.

The electromagnetic valve **18** includes an excitation coil **18***a*, a valve body **18***b*, and a spring **18***c*. The valve body **18***b* is located in the pressurizing chamber **14** and driven by the excitation coil **18***a*. The spring **18***c*, which functions as an urging member, urges the valve body **18***b* away from a valve seat **18***d* provided about the fuel inlet **16**. The valve seat **18***d* is located in an inner wall of the pressurizing chamber **14** that faces the valve body **18***b*. When the excitation coil **18***a* is supplied with current, the valve body **18***b* is moved towards the valve seat **18***d* against the force of the spring **18***c*, and contacts the valve seat **18***d*. As a result, the fuel inlet **16** is closed by the valve body **18***b*, and the pressurizing chamber **14** is disconnected from the fuel inlet **16**. When current to the excitation coil **18***a* is stopped, the valve body **18***b* is moved away from the valve seat **18***d* by the force of the spring **18***c*, and opens the fuel inlet **16**. Accordingly, the pressurizing chamber **14** is connected with the fuel inlet **16**. The electromagnetic valve **18** is configured as an internally opening valve that is opened when the valve body **18***b* in the pressurizing chamber **14** moves towards the interior of the pressurizing chamber **14**.

A process for controlling current to the electromagnetic valve **18** when the crank angle is identified will now be described with reference to FIGS. **2**(A) to **3**(C). The process is executed by the ECU **34**. FIGS. **2**(A) to **2**(C) show a suction stroke of the high pressure fuel pump **2**, and FIGS. **3**(A) to (C) show a pressurizing stroke of the high pressure fuel pump **2**. In a suction stroke, the excitation coil **18***a* of the electromagnetic valve **18** is supplied with no current, and the electromagnetic valve **18** is opened. In this case, as the plunger **12** moves along the states of FIG. **2**(A), FIG. **2**(B), and FIG. **2**(C) in this order, the volume of the pressurizing chamber **14** is increased. That is, the pressurizing chamber **14** is expanded. Accordingly, low-pressure fuel is drawn into the pressurizing chamber **14** from the low pressure fuel passage **20** through the fuel inlet **16**.

When the high pressure fuel pump **2** proceeds from a suction stroke to a pressurizing stroke, the plunger **12** moves along the states of FIG. **3**(A), FIG. **3**(B), FIG. **3**(C) in this order. Accordingly, the volume of the pressurizing chamber **14** is decreased. That is, the pressurizing chamber **14** is compressed. As shown in FIG. **3**(A) the excitation coil **18***a* is not supplied with current at initial stages of a pressurizing stroke. The electromagnetic valve **18** is therefore open. Thus, some of the fuel in the pressurizing chamber **14** is returned to the low pressure fuel passage **20** from the fuel inlet **16**, and the pressure of the fuel in the pressurizing chamber **14** is not increased and maintained low. Thereafter, the excitation coil **18***a* is supplied with current at a timing computed by the ECU **34**. Then, as shown in FIG. **3**(B), the valve body **18***b* contacts the valve seat **18***d* against the force of the spring **18***c* during a pressurizing stroke. As a result, the fuel inlet **16** is closed, and the pressure of the fuel in the pressurizing chamber **14** is increased. The pressurized fuel pushes open the check valve **26** shown in FIG. **1** and is sent to the delivery pipe **30** through the high pressure fuel passage **28**.

After the pressure in the pressurizing chamber **14** is increased, the increased pressure is maintained until the next suction stroke is started. Therefore, even after current to the excitation coil **18***a* is stopped, the valve body **18***b* continues contacting the valve seat **18***d* against the force of the spring **18***c* due to the difference between the high pressure in the pressurizing chamber **14** and the low pressure in the low pressure chamber **20**. When the high pressure fuel pump **2** proceeds from a pressurizing stroke to a suction stroke, the pressure in the pressurizing chamber **14** is lowered as the volume of he pressurizing chamber **14** is increased. Accordingly, the valve body **18***b* is moved away from the valve seat **18***d* by the force of the spring **18***c*, which opens the electromagnetic valve **18**.

While the camshaft **6** rotates one turn, in other words, while the crankshaft **5** rotates two turns, the plunger **12** reciprocates two times. Accordingly, the pump cycle including a suction stroke and a pressurizing stroke is repeated two times.

When the crank angle is identified, the ECU **34** is capable of identifying the rotational phase angle of the cam **8**, which rotates synchronously with the crankshaft **5**, based on the crank angle, that is, the ECU **34** is capable of identifying the stroke position of the high pressure pump **2** (the plunger **12**). Therefore, when the crank angle is identified, the ECU **34** is capable of determining timing for switching strokes of the high pressure pump **2** and of setting timing for starting current supply to the excitation coil **18***a* in relation to the stroke switching timing. For example, while the camshaft **6** rotates one turn (corresponding to two turns of the crankshaft **5**) as shown in FIG. **4**, the ECU **34** is capable of setting the timing for starting current supply to the excitation coil **18***a* to correspond to desired crank angles θa, θb. As a result, the amount of high-fuel pressure fuel supplied to the fuel injection system including the delivery pipe **30** and the fuel injection valve **32** is adjusted, so that the fuel pressure Pf in the fuel injection system is adjusted to a target value. If the current supply starting crank angles θa, θb in a pressurizing stroke are advanced, the amount of high pressure fuel sent to the fuel injection system is increased, and the fuel pressure Pf is increased. If the current supply starting crank angles θa, θb are delayed, the amount of high pressure fuel sent to the fuel injection system is decreased, and the fuel pressure Pf is lowered.

As described above, the crank angle cannot be identified when the engine **4** is being cranked until a first reference crank angle signal G2 is generated. Therefore, the stroke position of the plunger **12**, which is interlinked with the crankshaft **5**, cannot be identified, and the current control as shown in FIG. **4** cannot be performed. Thus, when the crank angle cannot be identified, or when the engine **4** is being cranked, the ECU **34** performs a duty control process shown in FIG. **5** to control a current to the electromagnetic valve **18**, thereby sending pressurized fuel to the fuel injection system.

The duty control process will now be described with reference to FIG. **5**. The process of FIG. **5** is repeatedly executed at a given interval, for example 24 ms, after the ECU **34** is turned on. When the process is started, the ECU

34 executes step **S100**. In step **S100**, the ECU **34** determines whether cranking of the engine **4** has been started (whether the starter **46** has been actuated) and the crank angle is yet to he identified. That is, the ECU **34** determines whether the crank angle is yet to be identified. If the crank angle is yet to be identified, the ECU **34** proceeds to step **S102**. In step **S102**, the ECU **34** uses a duty map Dmap shown in FIG. **6** for computing a duty ratio Dton that corresponds to a current battery voltage Vb.

The duty ratio Dton represents a ratio of time in which current is supplied to the excitation coil **18***a* (current supplying period) to the execution cycle of the duty control, which is 24 ms. In the map Dmap shown in FIG. **6**, the duty ratio Dton increases as the battery voltage Vb is lowered.

If the battery voltage Vb is lowered when the engine **4** is being cranked, time from when supply of current to the excitation coil **18***a* is started to when the electromagnetic force generated by the excitation coil **18***a* is sufficiently increased is extended. Then, the valve body **18***b* cannot contact the valve seat **18***d* in each current supplying period in the duty control, which may result in an insufficient closing of the electromagnetic valve **18**. That is, if the magnitude of the electromagnetic force generated at the excitation coil **18***a* is slowly increased, current is stopped before the valve body **18***b* reaches the valve seat **18***d* even if current supply to the excitation coil **18***a* is started. Thus, to completely close the electromagnetic valve **18** in at least part of each current supplying period of the excitation coil **18***a* even if the battery voltage Vb is low, the duty map Dmap shown in FIG. **6** is defined based on experiments, so that the ratio of the current supplying period is increased as the battery voltage Vb is lowered.

In step **S104** of FIG. **5**, the ECU **34** controls the drive circuit **50** such that the drive circuit **50** executes a duty control according to the duty ratio Dton computed in the above described manner. That is, the ECU **34** commands the drive circuit **50** to supply current to the excitation coil **18***a* in a period computed by a formula (Dton/100)×24 ms from the present moment, and to stop current to the excitation coil **18***a* after the computed period. Then, the ECU **34** temporarily suspends the process.

Thereafter, as long as the crank angle is unidentified (the positive outcome in step **S100**), the ECU **34** sets the duty ratio Dton according to the battery voltage Vb and continues duty controlling the excitation coil **18***a*.

If the crank angle is identified (negative outcome in step **S100**), the ECU **34** proceeds to **S106**. In step **S106**, the ECU **34** stops duty control and temporarily suspends the process. Then, as shown in FIG. **4**, a normal current control according to the crank angle is started.

One example of the process according to this embodiment is shown in the timing chart of FIG. **7**. When the starter **46** is actuated at time t0, that is, when cranking of the engine **4** is started, the duty control process of FIG. **5** is executed since the crank angle is first unidentified. Accordingly, current is supplied and stopped to the excitation coil **18***a* at short cycles. At this time, each current supplying period is extended according to the duty map Dmap as the battery voltage Vb is lowered so that the electromagnetic valve **18** is completely closed in at least part of each current supplying period of the excitation coil **18***a*.

In the example of FIG. **7**, the high pressure fuel pump **2** is in a suction stroke from time t0 to time t1. In the duty control during the suction stroke, the electromagnetic valve **18** is closed in the latter half of the current supplying period of the excitation coil **18***a*. That is, the electromagnetic valve **18** is closed at a little delay after the current supply to the excitation coil **18***a* is started. When no current is supplied to the excitation coil **18***a*, or during a current stopping period, the electromagnetic valve **18** is opened. When the electromagnetic valve **18** is opened, low pressure fuel is drawn into the pressurizing chamber **14** from the low pressure fuel passage **20** through the fuel inlet **16**.

From time t1 to time t3, the high pressure fuel pump **2** is in a pressurizing stroke. In the duty control during the pressurizing stroke, the valve body **18***b* contacts the valve seat **18***d* and the electromagnetic valve **18** is closed at time t2, which is a little later from when current supply to the excitation coil **18***a* is started. Accordingly, the pressure in the pressurizing chamber **14** is increased as the plunger **12** is moved. The increased pressure prevents the valve body **18***b* from separating the valve seat **18***d* even if the current to the excitation coil **18***a* is stopped afterwards. Thus, from time t2 to time t3, which is when the pressurizing stroke ends, the electromagnetic valve **18** is kept closed regardless how many times the current to the excitation coil **18***a* is stopped. In the period from time t2 to time t3, high pressure fuel in the pressurizing chamber **14** pushes open the check valve **26** and is sent to the delivery pipe **30**.

When the high pressure pump **2** proceeds to a suction stroke (from time t3 to time t5), the electromagnetic valve **18**, which is being duty controlled, repeatedly opens and closes according to stopping and supplying of current as in the previous suction stroke (from time t0 to time t1). In the example of FIG. **7**, the crank angle is identified at time t4, which is in this suction stroke. Therefore, after time t4, control is shifted from the duty control to the normal control of the electromagnetic valve **18**, which is described referring to FIG. **4**. That is, since time t4, at which the crank angle is identified, is in a suction stroke, no current is supplied to the excitation coil **18***a* from time t4 to time t5, which is the end of the suction stroke, to keep the electromagnetic valve **18** open.

Although a pressurizing stroke starts at time t5, the cranking of the engine **4** is not yet completed at time t5, and the fuel pressure Pf is not sufficiently increased. Therefore, current is supplied to the excitation coil **18***a* at time t5 to increase the fuel pressure Pf. As a result, the electromagnetic valve **18** is closed at time t6, which is slightly later than time t5. As described above, the pressure in the pressurizing chamber **14** is increased once the electromagnetic valve **18** is closed in a pressurizing stroke, and the electromagnetic valve **18** is kept closed until the end of the pressurizing stroke even if the current to the excitation coil **18***a* is stopped. Therefore, current to the excitation coil **18***a* is stopped at time t7, which is in the pressurizing stroke. From time t6 to time t8, which is the end of the pressurizing stroke, the electromagnetic valve **18** is kept closed. During this period, high pressure fuel is supplied to the delivery pipe **30** from the pressurizing chamber **14**.

When a suction stroke is started at time t8, the pressure in the pressurizing chamber **14** is lowered, which causes the electromagnetic valve **18** to be opened by the force of the spring **18***c*. Afterwards, the normal process, in which the electromagnetic valve **18** is opened in a suction stroke and is closed in a pressurizing stroke, is repeated so that the fuel pressure Pf in the fuel injection system is increased to a target fuel pressure.

In the prior art, each current supplying period in a duty control is not extended even if the battery voltage Vg is low. Therefore, even if supplying and stopping of current to the excitation coil **18***a* are repeated in the initial pressurizing stroke (refer to the period from time t1 to time t3 in FIG. **7**), the valve body **18***b* cannot contact the valve seat **18***d* in each current supplying period. In other words, the electromagnetic valve **18** cannot be completely closed. Thus, in the initial pressurizing stroke, the pressure of the fuel in the pressurizing chamber **14** is not increased, and fuel is not supplied to the delivery pipe **30**. Therefore, high pressure fuel is not supplied to the delivery pipe **30** at least until the next pressurizing stroke. As a result, compared to this embodiment, the pressure of the fuel injection system is increased with a delay, at least, of 0.3 to 0.5 seconds.

This embodiment provides the following advantages.

When the crank angle is yet to be identified while the engine **4** is being cranked, the amount of supplied fuel cannot be adjusted according to the crank angle unlike the case show in FIG. **4**. Therefore, in this embodiment, the electromagnetic valve **18** is controlled according to the duty control process shown in FIG. **5** In the duty control process, the duty ratio Dton is increased as the battery voltage Vg is lowered according to the duty map Dmap, thereby extending each current supplying period. Accordingly, as shown in the timing chart of FIG. **7**, closing of the electromagnetic valve **18** in each current supplying period, particularly closing of the electromagnetic valve **18** in a pressurizing stroke as shown at time t2, is reliably performed. As a result, even if the battery voltage Vb is low when the crank angle is unidentified, the pressure of fuel supplied to the fuel injection system is effectively increased compared to the prior art.

Therefore, when the engine **4** is being cranked, the pressure of fuel in the fuel injection system is increased to a target value at an early stage, which allows fuel to be reliably injected. This permits the engine **4** to be smoothly started.

Even if the crank angle is not identified, each current supplying period is gradually shortened (or maintained short) if the battery voltage Vb is gradually increased (or if the battery voltage Vb is high from the beginning). Therefore, load on the electrical circuit including the drive circuit **50** and the excitation coil **18***a* is prevented from increasing.

A second embodiment of the present invention will now be described with reference to FIGS. **8** and **9**. The differences from the first embodiment of FIGS. **1** to **7** will mainly be discussed.

This embodiment is different from the first embodiment in that, when the engine **4** is being cranked, a duty control process of FIG. **8** is performed instead of the duty control process of FIG. **5**. Like the duty control process of the first embodiment, the duty control process of this embodiment is performed to control the excitation coil **18***a* of the electromagnetic valve **18** before the crank angle is identified. However, in this embodiment, the duty ratio is not varied according to the battery voltage Vb but is fixed to a given value (for example, 50%). Instead, the cycle of the duty control is varied according to the battery voltage Vb.

The duty control process of this embodiment will now be described with reference to a flowchart of FIG. **8**. The process is repeatedly executed at a given interval, for example 8 ms, after the ECU **34** is turned on. When the process is started, the ECU **34** determines whether cranking of the engine **4** has been started and the crank angle is yet to be identified in step S**200**. If the crank angle is yet to be identified, the ECU **34** proceeds to step S**202**, and determines whether the battery voltage Vb is less than a predetermined first determination value V1. If the battery voltage Vb is less than the first determination value V1, the ECU **34** proceeds to step S**204**, and determines whether the battery voltage Vb is less than a predetermined second determination value V2. The second determination value V2 is less than the first determination value V1.

If the battery voltage Vb is less than the second determination value V2, the ECU **34** proceeds to step S**206**, and sets the cycle of the duty control to 32 ms. In step S**208**, the ECU **34** controls the drive circuit **50** to perform the duty control of the set cycle of 32 ms. Then, the ECU **34** temporarily suspends the process.

Therefore, if the battery voltage Vb is less than the second determination value V2, the duty control at a cycle of 32 ms is performed with a constant duty ratio to the excitation coil **18***a* of the electromagnetic valve **18**. Thus, when the duty ratio is set to 50%, each current supplying period is 16 ms in the duty control.

Thereafter, when the battery voltage Vb is raised to be equal to or higher than the second determination value V2 and less than the first determination value V1, the outcome of step S**204** is negative. In this case, the ECU **34** proceeds to step S**210**. In step S**210**, the ECU **34** sets the cycle of the duty control to 16 ms and proceeds to step S**208**. Therefore, if the battery voltage Vb is equal to or higher than the second determination value V2 and less than the first determination value V1, a duty control at a cycle of 16 ms is performed with a constant duty ratio (50%) to the excitation coil **18***a* of the electromagnetic valve **18**. Each current supplying period of the duty control is 8 ms.

Thereafter, when the battery voltage Vb is increased to a value equal to or greater than the first determination value V1, the outcome of step S**202** is negative. In this case, the ECU **34** proceeds to step S**212**. In step S**212**, the ECU **34** sets the cycle of the duty control to 8 ms and proceeds to step S**208**. Therefore, if the battery voltage Vb is equal to or higher than the first determination value V1, a duty control at a cycle of 8 ms is performed with a constant duty ratio (50%) to the excitation coil **18***a* of the electromagnetic valve **18**. Each current supplying period of the duty control is 4 ms.

As long as the crank angle is unidentified (the positive outcome in step S**200**), the ECU **34** sets the cycle of the duty ratio according to the battery voltage Vb and continues duty controlling the excitation coil **18***a*.

If the crank angle is identified (negative outcome in step S**200**), the ECU **34** proceeds to S**214**. In step S**214**, the ECU **34** stops the duty control and temporarily suspends the process. Afterwards, as long as the crank angle is identified, a normal current control according to the crank angle is executed (see FIG. **4**).

One example of the process according to this embodiment is shown in the timing chart of FIG. **9**. When the starter **46** is actuated at time t20, the duty control process of FIG. **8** is executed until time t26, at which the crank angle is identified. Accordingly, current is supplied and stopped to the excitation coil **18***a* at short cycles. In the period from t20, to time t23, in which the battery voltage Vb is less than the second determination value V2, the cycle of the duty control is set to 32 ms. In the period from t23 to time t25, in which the battery voltage Vb is equal to or higher than the second determination value V2 and less than the first determination value V1, the cycle of the duty control is set to 16 ms. In the period from t25, at which the battery voltage Vb is equal to or higher than the first determination value V1, to time t26, the cycle of the duty control is set to 8 ms.

During the above described duty control, the electromagnetic valve **18** is repeatedly closed and opened in accordance with supplying and stopping of current in the period of each suction stroke of the high pressure pump **2** (the period from time t20 to time t21, and the period from t24 to t26). When the electromagnetic valve **18** is opened, low pressure fuel is drawn into the pressurizing chamber **14** from the low pressure fuel passage **20** through the fuel inlet **16**.

In a pressurizing stroke from time t21 to time t24, the electromagnetic valve **18** is closed at t22. Afterwards, the electromagnetic valve **18** is kept closed due to an increased pressure of the pressurizing chamber **14** until time t24, which is the end of the pressurizing stroke, regardless how many times current to the excitation coil **18***a* is stopped. In the period from time t22 to time t24, in which the electromagnetic valve **18** is closed, high pressure fuel in the pressurizing chamber **14** pushes open the check valve **26** and is sent to the delivery pipe **30**.

In a suction stroke from time t24 to time t27, the crank angle is identified at t26. Therefore, after time t26, the control is shifted from the duty control to the normal control for the electromagnetic control described referring to FIG. **4**. That is, the normal process, in which the electromagnetic valve **18** is opened in a suction stroke and is closed in a pressurizing stroke, is repeated so that the fuel pressure Pf is increased to a target fuel pressure.

In the prior art, the cycle of the duty control is not extended even if the battery voltage Vg is low, and each current supplying period of the duty control is not extended. Therefore, in the initial pressurizing stroke (refer to the period from time t21 to t24 in FIG. **9**), the pressure of the fuel in the pressurizing chamber **14** is not increased, and the fuel is not supplied to the delivery pipe **30**. Therefore, compared to this embodiment, the pressure increase in the fuel injection system is delayed.

This embodiment provides the following advantages.

In the duty control of this embodiment, the cycle of the duty control is extended as the battery voltage Vb is lowered, thereby extending each current supplying period. Accordingly, as shown in the timing chart of FIG. **9**, closing of the electromagnetic valve **18** in each current supplying period, particularly as shown at time t22, closing of the electromagnetic valve **18** in a pressurizing stroke, is reliably performed. As a result, even if the battery voltage Vb is low when the crank angle is unidentified, the pressure of fuel supplied to the fuel injection system is effectively increased compared to the prior art.

Therefore, when the engine **4** is being cranked, the pressure of fuel in the fuel injection system is increased to a target value at an early stage, which allows fuel to be reliably injected. This permits the engine **4** to be smoothly started.

Even if the crank angle is not identified, the cycle of the duty control is gradually shortened (or maintained short) if the battery voltage Vb is gradually increased (or if the battery voltage Vb is high from the beginning). Therefore, each current supplying period in the duty control is not unnecessarily extended, and thus load on the electrical circuit including the drive circuit **50** and the excitation coil **18***a* is prevented from unnecessarily increasing.

When the battery voltage Vb is low, each current supplying period is extended not only by increasing the ratio of the current supplying period to one cycle of the duty control but by extending the cycle of the duty control. Therefore, the duty ratio does not need to be changed. This effectively prevents the load on the electrical circuit from increasing.

Further, the cycle of the duty control is shortened (or maintained short) if the battery voltage Vb is increased (or is high from the beginning). Accordingly, the probability that the electromagnetic valve **18** is closed at an early stage of the pressurizing stroke is increased. This is advantageous to guarantee that a sufficient amount of high pressure fuel be supplied to the fuel injection system, and the fuel pressure Pf is further effectively increased.

A third embodiment of the present invention will now be described with reference to FIGS. **10** and **12**. The differences from the first embodiment of FIGS. **1** to **7** will mainly be discussed. This embodiment is different from the first embodiment in that, when the engine **4** is being cranked, a duty control process of FIG. **10** is performed instead of the duty control process of FIG. **5**.

The duty control process of this embodiment will now be described with reference to a flowchart of FIG. **10**. The process is repeatedly executed at a given interval, for example 8 ms, after the ECU **34** is turned on. When the process is started, the ECU **34** determines whether cranking of the engine **4** has been started and whether the crank angle is yet to be identified in step **S300**. If the crank angle is yet to be identified, the ECU **34** proceeds to step **S302**. In step **S302**, the ECU **34** uses a current supplying period map Tmap shown in FIG. **11** for computing a current supplying period Ton that corresponds to the battery voltage Vb.

The current supplying period Ton represents the duration of the current supplying period in one cycle of the duty control. In the current supplying period map Tmap of FIG. **11**, the current supplying period Ton is set longer for lower values of the battery voltage Vb. However, if the battery voltage Vb is less than a predetermined low voltage Vx, the current supplying period Ton is maintained at an uppermost value, or 16 ms. Also, if the battery voltage Vb is equal to or higher than a predetermined high voltage Vz, the current supplying period Ton is maintained at a lowermost value, or 4 ms.

In step **S304**, the ECU **34** determines whether the computed current supplying period Ton is equal to or less than 8 ms. If the current supplying period Ton is longer than 8 ms, the ECU **34** proceeds to step **S312**, and sets the cycle of the duty control to 32 ms. In step **S310**, the ECU **34** controls the drive circuit **50** to perform a duty control of the cycle of 32 ms with the computed current supplying period Ton. Then, the ECU **34** temporarily suspends the process.

Therefore, in one cycle of the duty control to the electromagnetic valve **18**, the excitation coil **18***a* is supplied with current for the current supplying period Ton. Thereafter, the current to the excitation coil **18***a* is stopped for a period computed by subtracting the current supplying period Ton from 32 ms.

Thereafter, if the battery voltage Vb is increased, the current supplying period Ton is gradually shortened every time the routine of FIG. **10** is executed. However, unless the current supplying period Ton is equal to or less than 8 ms, the cycle of the duty control is maintained at 32 ms. Accordingly, the duty ratio (the ratio of the current supplying period Ton to 32 ms) is gradually decreased.

When the current supplying period Ton is shortened to be equal to or less than 8 ms as the battery voltage Vb increases, the outcome of step **S304** is positive, and the ECU **S306** proceeds to step **S306**. The fact that the current supplying period Ton is equal to or less than 8 ms indicates that the duty ratio is maintained equal to or less than 50% even if the cycle of the duty ratio is changed to 16 ms. In step **S306**, the ECU **34** determines whether the computed current supplying period Ton is equal to 4 ms. If the current supplying period Ton is not equal to 4 ms, that is, if the current supplying period Ton is longer than 4 ms, which is the lowermost value, the ECU **34** proceeds to step **S314**, and sets the cycle of the duty control to 16 ms. In step **S310**, the ECU **34** controls the drive circuit **50** to perform a duty control of the cycle of 16 ms with the current supplying period Ton computed in step **S302**. Then, the ECU **34** temporarily suspends the process.

Thereafter, if the battery voltage Vb is increased, the current supplying period Ton is gradually shortened every time the routine of FIG. **10** is executed. However, unless the current supplying period Ton is equal to or less than 4 ms, the cycle of the duty control is maintained at 16 ms. Therefore, the duty ratio is gradually decreased.

When the current supplying period Ton is shortened to be equal to or less than 4 ms as the battery voltage Vb increases, the outcome of step **S306** is positive, and the ECU **S306** proceeds to step **S308**. In step **S308**, the ECU **34** sets the cycle of the duty control to be 8 ms. The fact that the current supplying period Ton is equal to or less than 4 ms indicates that the duty ratio becomes 50% when the cycle of the duty control is changed to 8 ms. In step **S310**, the ECU **34** controls the drive circuit **50** to perform a duty control of the cycle of 8 ms with the current supplying period Ton computed in step **S302**. Then, the ECU **34** temporarily suspends the process.

Afterwards, the duty control of the cycle of 8 ms is continued at the duty ratio of 50% until the crank angle is identified.

If the crank angle is identified (negative outcome in step **S300**), the ECU **34** proceeds to **S316**. In step **S316**, the ECU **34** stops the duty control and temporarily suspends the process. Afterwards, as long as the crank angle is identified, a normal current control according to the crank angle is executed (see FIG. **4**).

One example of the process according to this embodiment is shown in the timing chart of FIG. **12**. When the starter **46** is actuated at time t40, the duty control process of FIG. **10** is executed until time t46, at which the crank angle is identified. Accordingly, current is supplied and stopped to the excitation coil **18***a* at short cycles. At this time, the period from when the current supply to the excitation coil **18***a* is started to when the electromagnetic valve **18** is opened is gradually shortened as the battery voltage Vb is increased. Accordingly, the current supplying period Ton is gradually shortened based on the current supplying period map Tmap of FIG. **11**.

During the above described duty control, the battery voltage Vb is lower than an intermediate voltage Vy in a period from time t40 to t43, and thus, the current supplying period Ton is longer than 8 ms. In the period from t40 to time t43, the cycle of the duty control is set to 32 ms. In a period from time t43 to t45, the battery voltage Vb is equal to or higher than the intermediate voltage Vy and lower than the high voltage Vz. Thus, the current supplying period Ton is equal to or less than 8 ms and longer than 4 ms. In the period from t43 to time t45, the cycle of the duty control is set to 16 ms. In a period from time t45 to time t46, the battery voltage Vb is equal to or higher than the high voltage Vz, and thus, the current supplying period Ton is set to 4 ms. In the period from t45 to time t46, the cycle of the duty control is set to 8 ms. That is, although the current supplying period Ton and the cycle of the duty control are shortened as the battery voltage Vb is increased, the cycle of the duty control is discretely shortened so that that the duty ratio does not exceed 50%, which is a predetermined acceptable value.

During the above described duty control, the electromagnetic valve **18** is repeatedly closed and opened in accordance with supplying and stopping of current in the period of each suction stroke of the high pressure pump **2** (the period from time t40 to time t41, and the period from t44 to t46). When the electromagnetic valve **18** is opened, low pressure fuel is drawn into the pressurizing chamber **14** from the low pressure fuel passage **20** through the fuel inlet **16**.

In a pressurizing stroke from time t41 to time t44, the electromagnetic valve **18** is closed at t42. Afterwards, the electromagnetic valve **18** is kept closed until time t44, which is the end of the pressurizing stroke, regardless how many times the current to the excitation coil **18***a* is stopped. In the period from time t42 to time t44, in which the electromagnetic valve **18** is closed, high pressure fuel in the pressurizing chamber **14** pushes open the check valve **26** and is sent to the delivery pipe **30**.

In a suction stroke from time t44 to time t47, the crank angle is identified at t46. Therefore, after time t46, the control is shifted from the duty control to the normal control for the electromagnetic control described referring to FIG. **4**. That is, the normal process, in which the electromagnetic valve **18** is opened in a suction stroke and is closed in a pressurizing stroke, is repeated so that the fuel pressure Pf is increased to a target fuel pressure.

In the prior art, the cycle and the current supplying period in a duty control are not extended even if the battery voltage Vb is low. Therefore, in the initial pressurizing stroke (refer to the period from time t41 to t44 in FIG. **12**), the pressure of the fuel in the pressurizing chamber **14** is not increased, and the fuel is not supplied to the delivery pipe **30**. Therefore, compared to this embodiment, the pressure increase in the fuel injection system is delayed.

This embodiment substantially has the same advantages as the first and second embodiments. If the battery voltage Vb is high, the cycle of the duty control is shortened to a level at which the duty ratio does not exceed 50%. Therefore, the ratio of the current supplying period in the duty control is not unnecessarily increased, and the load on the electric circuit is effectively prevented from increasing.

The present invention may be modified as follows.

In the second embodiment of FIGS. **8** and **9**, the cycle of the duty control is discretely changed according to the battery voltage Vb. However, the cycle of the duty control may be continuously changed. In the first embodiment of FIGS. **1** to **7** and in the third embodiment of FIGS. **10** to **12**, the current supplying period in the duty control (duty ratio) may be discretely changed according to the battery voltage Vb.

In the illustrated embodiments, the high pressure fuel pump is controlled to adjust the supply amount of pressurized fuel in each pressurizing stroke after the crank angle is identified. That is, after the crank angle is identified, the electromagnetic valve **18** is opened in the entire suction stroke. In the pressurizing stroke, the electromagnetic valve **18** is closed in a crank angle range that corresponds to the amount of fuel to be sent to the delivery pipe **30** (see FIG. **4**). However, the high pressure fuel pump may be controlled to adjust the supply amount of pressurized fuel in suction strokes after the crank angle is identified. For example, during a suction stroke after the crank angle is identified, current to electromagnetic valve **18** may be stopped to open the electromagnetic valve **18** in a crank angle range corresponding to the amount of fuel to be sent to the delivery pipe **30** (a range from θc to θd and a range from θe to θf), so that fuel is drawn into the pressurizing chamber **14** only in these crank angle ranges. The electromagnetic valve **18** is closed in the entire pressurizing stroke. In this case, the supply amount of pressurized fuel is decreased if the current supply starting crank angles θd, θf are advanced. The supply amount of pressurized fuel is increased if the current supply starting crank angles θd, θf are delayed.

Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

What is claimed is:

1. A high pressure fuel supplying apparatus, which pressurizes fuel supplied from a fuel supply source and sends the pressurized fuel to a fuel injection system of an internal combustion engine, the apparatus comprising:

a fuel pump having a pressurizing chamber, wherein the fuel pump repeats a pressurizing stroke and a suction stroke in accordance with rotation of the engine, wherein, during each suction stroke, the fuel pump draws fuel from the fuel supply source to the pressurizing chamber, and wherein, during each pressurizing stroke, the fuel pump pressurizes fuel in the pressurizing chamber and sends the pressurized fuel to the fuel injection system;

an electromagnetic valve that selectively connects and disconnects the pressurizing chamber with the fuel supply source, wherein the electromagnetic valve is actuated by electricity supplied from a power supply;

a voltage detecting device, which detects a voltage of the power supply; and

a controller, which controls the electromagnetic valve, wherein, to adjust an amount of fuel to be supplied to the fuel injection system, the controller determines opening and closing timing of the electromagnetic valve based on a rotational phase of the engine, wherein, when the rotational phase of the engine is not identified, the controller executes a duty control to cyclically repeat supplying and stopping of current to the electromagnetic valve, and wherein the controller extends a current supplying period in each cycle of the duty control as the voltage detected by the voltage detecting device is lowered.

2. The apparatus according to claim **1**, wherein the controller continuously changes the current supplying period according to the voltage detected by the voltage detecting device.

3. The apparatus according to claim **1**, wherein the controller discretely changes the current supplying period according to the voltage detected by the voltage detecting device.

4. The apparatus according to claim **1**, wherein the controller changes the duty ratio for changing the current supplying period.

5. The apparatus according to claim **1**, wherein the controller changes the cycle of the duty control for changing the current supplying period.

6. The apparatus according to claim **1**, wherein, when the rotational phase of the engine is not identified, the controller, in addition to extending the current supplying period, extends the cycle of the duty control as the voltage detected by the voltage detecting device is lowered, and wherein the controller sets the cycle of the duty control such that the duty ratio does not exceed a predetermined acceptable value.

7. The apparatus according to claim **1**, wherein the electromagnetic valve includes a valve body located in the pressurizing chamber, wherein a valve seat is provided at a part of an inner wall of the pressurizing chamber that faces the valve body, wherein, when supply of current to the electromagnetic valve is started, the valve body is moved toward and contacts the valve seat, and wherein current to the electromagnetic valve is stopped, the valve body is moved toward the interior of the pressurizing chamber away from the valve seat.

8. The apparatus according to claim **1**, wherein the electromagnetic valve has a valve body and an urging member, wherein the valve body is capable of moving between a closed position for disconnecting the pressurizing chamber from the fuel supply source and an open position for connecting the pressurizing chamber with the fuel supply source, wherein the urging member urges the valve body toward the open position, wherein, when current is supplied to the electromagnetic valve, the valve body is moved to the closed position against the force of the urging member, and wherein, when current is not supplied to the electromagnetic valve, the valve body is moved to the open position by the force of the urging member.

9. The apparatus according to claim **8**, wherein, when the valve body is moved to the closed position during a pressurizing stroke of the fuel pump, the pressure in the pressurizing chamber acts on the valve body to retain the valve body at the closed position.

10. The apparatus according to claim **7**, wherein the controller determines a stroke position of the fuel pump based on the rotational phase of the engine, wherein, when the fuel pump is at a suction stroke, the controller stops current to the electromagnetic valve, and wherein, when the fuel pump is at a pressurizing stroke, the controller starts supplying current to the electromagnetic valve at timing that corresponds to the amount of fuel to be supplied to the fuel injection system.

11. The apparatus according to claim **7**, wherein the controller determines a stroke position of the fuel pump based on the rotational phase of the engine, wherein, when the fuel pump is at a suction stroke, the controller stops current to the electromagnetic valve for a period that corresponds to the amount of fuel to be supplied to the fuel injection system, and wherein, when the fuel pump is at a pressurizing stroke, the controller closes the electromagnetic valve.

12. A high pressure fuel supplying apparatus, which pressurizes fuel supplied from a fuel supply source and sends the pressurized fuel to a fuel injection system of an internal combustion engine, the apparatus comprising:

a fuel pump having a pressurizing chamber, wherein the fuel pump repeats a pressurizing stroke and a suction stroke in accordance with rotation of the engine, wherein, during each suction stroke, the fuel pump draws fuel from the fuel supply source to the pressurizing chamber, and wherein, during each pressurizing stroke, the fuel pump pressurizes fuel in the pressurizing chamber and sends the pressurized fuel to the fuel injection system;

an electromagnetic valve that selectively connects and disconnects the pressurizing chamber with the fuel supply source, wherein the electromagnetic valve is actuated by electricity supplied from a power supply, wherein the electromagnetic valve includes a valve body located in the pressurizing chamber, wherein a valve seat is provided at a part of an inner wall of the pressurizing chamber that faces the valve body, wherein the valve body is urged away from the valve seat by an urging member, wherein, when supply of current to the electromagnetic valve is started, the valve body is moved toward and contacts the valve seat against the force of the urging member, and wherein, when current to the electromagnetic valve is stopped, the valve body is moved toward the interior of the pressurizing chamber away from the valve seat by the force of the urging member;

a rotational phase detecting device, which detects a rotational phase of the engine;

a voltage detecting device, which detects a voltage of the power supply;

a controller, which controls the electromagnetic valve, wherein, to adjust an amount of fuel to be supplied to the fuel injection system, the controller determines opening and closing timing of the electromagnetic valve based on a rotational phase of the engine, wherein, when the rotational phase of the engine is not identified, the controller executes a duty control to cyclically repeat supplying and stopping of current to the electromagnetic valve, and wherein the controller extends a current supplying period in each cycle of the duty control as the voltage detected by the voltage detecting device is lowered.

13. The apparatus according to claim **12**, wherein the controller changes the duty ratio for changing the current supplying period.

14. The apparatus according to claim **12**, wherein the controller changes the cycle of the duty control for changing the current supplying period.

15. The apparatus according to claim **12**, wherein, when the rotational phase of the engine is not identified, the controller, in addition to extending the current supplying period, extends the cycle of the duty control as the voltage detected by the voltage detecting device is lowered, and wherein the controller sets the cycle of the duty control such that the duty ratio does not exceed a predetermined acceptable value.

16. The apparatus according to claim **12**, wherein, when the valve body contacts the valve seat during a pressurizing stroke of the fuel pump, the pressure in the pressurizing chamber acts on the valve body such that the valve body remains contacting the valve seat.

17. A method for controlling a high pressure fuel supplying apparatus for an internal combustion engine, wherein the apparatus includes a fuel pump having a pressurizing chamber and an electromagnetic valve, wherein the fuel pump repeats a pressurizing stroke and a suction stroke in accordance with rotation of the engine, wherein, during each suction stroke, the fuel pump draws fuel from a fuel supply source to the pressurizing chamber, and wherein, during each pressurizing stroke, the fuel pump pressurizes fuel in the pressurizing chamber and sends the pressurized fuel to a fuel injection system of the engine, wherein the electromagnetic valve is actuated by electricity supplied from a power supply to selectively connect and disconnect the pressurizing chamber with the fuel supply source, the method comprising:

determining opening and closing timing of the electromagnetic valve based on a rotational phase of the engine, thereby adjusting an amount of fuel to be supplied to the fuel injection system;

executing a duty control to cyclically repeat supplying and stopping of current to the electromagnetic valve when the rotational phase of the engine is not identified; and

extending a current supplying period in each cycle of the duty control as the voltage of the power supply is lowered.

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